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# Canadian Aeronautical Journal

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CANADIAN AERONAUTICAL INSTITUTE
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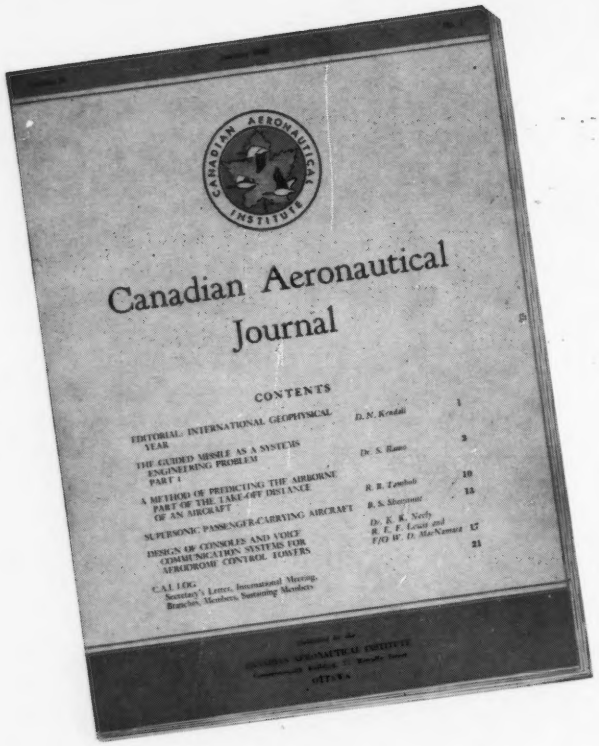
OTTAWA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Canadian Aeronautical Journal
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# *A first rate advertising medium*

**The following table gives a breakdown of the circulation of a recent issue.**

| Business Classification | Job Assignment | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Company and Organization | Management | Eng'g & Scientific | Associated Professions | Production | Main. & Field Service | Flight and Operation | Logistics | Sales & Public Relations | Students | Others |
| 1. AERONAUTICAL MANUFACTURERS | | | | | | | | | | | |
| (a) Aircraft & Missiles | 54 | 55 | 481 | 6 | 90 | 119 | 44 | 16 | 24 | 1 | 1 |
| (b) Powerplants & Engines | 49 | 18 | 73 | | 14 | 53 | 5 | 1 | 8 | | |
| (c) Components & Accessories | 103 | 72 | 125 | | 33 | 66 | 2 | 4 | 25 | | |
| (d) Materials & Supplies | 10 | 20 | 8 | | 3 | | | | 14 | | 1 |
| 2. GOVERNMENT | | | | | | | | | | | |
| Can. Armed Services | | | | | | | | | | | |
| (i) Commissioned Officers | 6 | 2 | 155 | 8 | 2 | 35 | 55 | 5 | | 3 | 1 |
| (ii) Other Ranks | | | 2 | | 1 | 39 | | | | | |
| (iii) Civilian DND & DRB | 3 | | 33 | 3 | 9 | 13 | | 1 | | | |
| Can. Civil Ser. NRC & DOT | 4 | 5 | 66 | 1 | 10 | 7 | 12 | 5 | | | |
| Prov. & Other Gov. Services | 2 | 2 | 2 | | | | | | | | |
| Foreign | 79 | 1 | 1 | 1 | | 1 | 2 | | | | |
| 3. SCIENTIFIC ORGANIZATIONS | | | | | | | | | | | |
| Commercial Laboratories | 4 | 1 | 3 | | | | | | | | |
| Universities & Schools | 35 | | 26 | 7 | | 1 | | | | 150 | 1 |
| 4. CONSULTANTS | | 1 | 9 | | | | | | | | |
| 5. AIRLINES & OPERATORS | | | | | | | | | | | |
| Can. Scheduled Airlines | 6 | 7 | 51 | | 2 | 61 | 12 | | 2 | | 1 |
| Can. Operators | | 15 | 8 | | 1 | 24 | 10 | | 1 | | |
| Foreign Airlines & Operators | | | 1 | | | 1 | | | | | |
| 6. AIRPORTS including Miscellaneous Flight Services | | | | | | 1 | | | | | |
| 7. PROFESSIONAL SOCIETIES TECHNICAL INFORMATION & LEGAL SERVICES | 37 | 11 | 1 | 7 | | | | | | | |
| 8. MISCELLANEOUS | 26 | 10 | 2 | 1 | 2 | 1 | 1 | | 3 | | 6 |
| TOTAL | 388 | 220 | 1047 | 34 | 167 | 422 | 143 | 32 | 77 | 154 | 11 |

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# NOTES AND APPLICATION FORM

# Canadian Aeronautical Institute

77 Metcalfe St., Ottawa 4, Ontario

*"To advance the art, science and engineering relating to aeronautics"*

## THE CANADIAN AERONAUTICAL INSTITUTE IS

a non-profit, technical society devoted to aeronautical matters. It has Headquarters and a permanent secretariat in Ottawa, and Branches at various centres of aeronautical activity in Canada. Its governing body is a Council, the members of which are elected by the voting members of the Branches; each Branch elects at least one of its members to serve on the Council. The Councillors elect a President from among themselves.

Besides the Branches, which serve members in certain localities, the structure of the Institute provides for the establishment of Specialist Sections to serve members specializing in certain fields of aeronautical work, regardless of their location. These Sections are responsible for the development of their particular subjects in the Institute's programmes and publications.

New Branches and Sections may be established at the discretion of the Council on application by the members concerned. The first requirement for the formation of a Branch is that a minimum of 20 members of the Institute reside in the district and can participate in the Branch functions.

Each Branch or Section is governed by an Executive Committee elected each year by the members concerned.

## BENEFITS OF MEMBERSHIP

To those who can participate in its activities, the Institute offers opportunities for informal contacts with people having broadly similar interests. It provides a medium through which each member can learn from others and make his own contributions to the common pool of knowledge and experience. Even to those who cannot play an active part, membership of the Institute gives a sense of belonging to the technical fraternity and automatically confers some status in the profession of aeronautics.

### Meeting Programme

The principal activity of the C.A.I. takes place in the Branches, each Branch presenting a series of lectures, plant visits etc. at monthly intervals during the winter months.

Three two-day meetings of the Institute as a whole are held every year. They are

1) A Joint Meeting with the Institute of the Aeronautical Sciences; held in the fall,
2) the Mid-season Meeting; usually held in February, and
3) the Annual General Meeting; usually held in May.

Symposia and other special technical meetings are also arranged from time to time.

### Publications

The Institute publishes the Canadian Aeronautical Journal, a monthly publication containing technical articles of a wide range of interest and news of the activities of the Institute, its Branches, Sections and members.

In addition the Institute issues a List of Members.

Preprints of papers presented at Institute meetings are prepared by the Institute and made available on the first day of each meeting.

## MEMBERSHIP REQUIREMENTS

Individual membership of the Institute is divided into seven grades, requiring the qualifications set out in the following table. Application for membership may be made on the attached form, which must be returned to the Secretary on completion. The applicant does not apply for membership in any specific grade; his grade is decided by an Admissions Committee, after careful study of the information given on his form and by his referees. In the event of an appeal against the Committee's grading, the Council is the deciding authority. On admission the applicant is informed of his grading and the appropriate entrance fees and dues.

In the course of time any member may apply for advancement in grade as his qualifications improve. There is a special form for this purpose.

| | Qualifications | Annual Dues | *Overseas Annual Dues |
|---|---|---|---|
| Student | Shall be undergoing a course of study in a school of engineering or technology recognized by the Council. | $ 3.00 | $ 2.00 |
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| Technical Member | Shall have been engaged in scientific, engineering, research, manufacturing or operational work in aeronautics or fields closely relating to aeronautics for at least four years, or shall have graduated from a school of engineering or science recognized by the Council. | $ 8.00 | $ 5.00 |
| Member | Shall have been engaged in aviation for at least eight years and shall have acquired a recognized standing in engineering, design, research, manufacture, instruction, test flying, the application of the aeronautical sciences, or the technical development of the operation of aircraft, aircraft power plants, or other essential components or accessories of aircraft. The period of eight years may be reduced to four years if the candidate for election has graduated from a school of engineering or science recognized by the Council. | $10.00 | $ 6.00 |
| Associate | Shall be engaged in an administrative or other position in aviation though ineligible for the technical grades. | $15.00 | $10.00 |
| Associate Fellow | Shall have been engaged for not less than ten years in the practice of aeronautical science or engineering; and shall have been in responsible charge of important scientific or engineering work in aeronautics, or shall have done original work of outstanding character, or shall have otherwise made outstanding contributions to aeronautical science or engineering. | $15.00 | $10.00 |
| Fellow | Shall have been an Associate Fellow for one year or more and shall have attained a position of distinction in aeronautics. He shall have made notable and valuable contributions in aeronautical science or engineering. | $15.00 | $10.00 |

## ENTRANCE FEES

The Entrance Fee is $5.00. Members in good standing in the R.Ae.S., I.A.S., I.A.T. or O.A.S. on the 1st January, 1954, who were resident in Canada at that time are admitted without payment of entrance fee. Students and Junior Members are also exempt from entrance fee but must pay a transfer fee, which is in effect a deferred entrance fee, when they transfer later on to one of the senior grades.

## *OVERSEAS ANNUAL DUES

Members not normally resident in Canada or the U.S.A. are entitled to the reduced rate of annual dues shown in the right-hand column of the above table.

## SUBSCRIPTION TO C.A.I. PUBLICATION

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# CANADIAN AERONAUTICAL INSTITUTE

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*Surname*

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*Dr., Mr., W/C etc.*

**Please complete the above in Capitals**

I hereby apply for membership in the Canadian Aeronautical Institute. I certify that all information I have given in this application is correct to the best of my knowledge, and that my references are personally familiar with my aeronautical qualifications.

If elected, I agree to abide by the By-laws and Regulations of the Canadian Aeronautical Institute. Upon termination of my membership, for any reason, I will not use the initials of the Institute after my name and will return, on request, any card, certificate, or insignia of membership.

Signature..... Date.....

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Code

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Grade

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Telephone Nos.: Business:..... Residence:.....

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Date and place of birth:..... Citizenship:.....

Business title, :
Firm name and :
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Firm's products, services:.....

Your present duties:.....

.....

.....

Service decorations, honorary awards, scholarships etc.....

.....

Date and No. of licence, certificate etc., if registered technician or pilot:.....

.....

Other aeronautical qualifications:.....

.....

Current membership in other technical or professional organizations:

Entry Date Grade of Membership Organization

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.....

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Technical papers: Title, where presented or published:

.....

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## ACADEMIC RECORD

| Dates | Name and Location of School | | Major Subject | Degree or Certificate |
|---|---|---|---|---|
| | Secondary Technical | | | |
| | University Tech. Inst. | | | |
| | Other Courses | | | |
| | Additional Certificates or Degrees | | | |

## OCCUPATIONAL RECORD

**Give an explicit summary of your qualifying experience, beginning with current status, then previous positions. Use additional sheet if required.**

| Dates | Employer's Name, Address, Services | Specific Title, Grade or Position | Nature of Duties, Degree of Responsibility, Supervision Involved |
|---|---|---|---|
| | | | |

## REFERENCES

**Name at least four people (of which at least two must be members of the C.A.I., R.Ae.S., I.A.S. or E.I.C.) acquainted with your aeronautical background**

| Name and Address |
|---|
| 1. |
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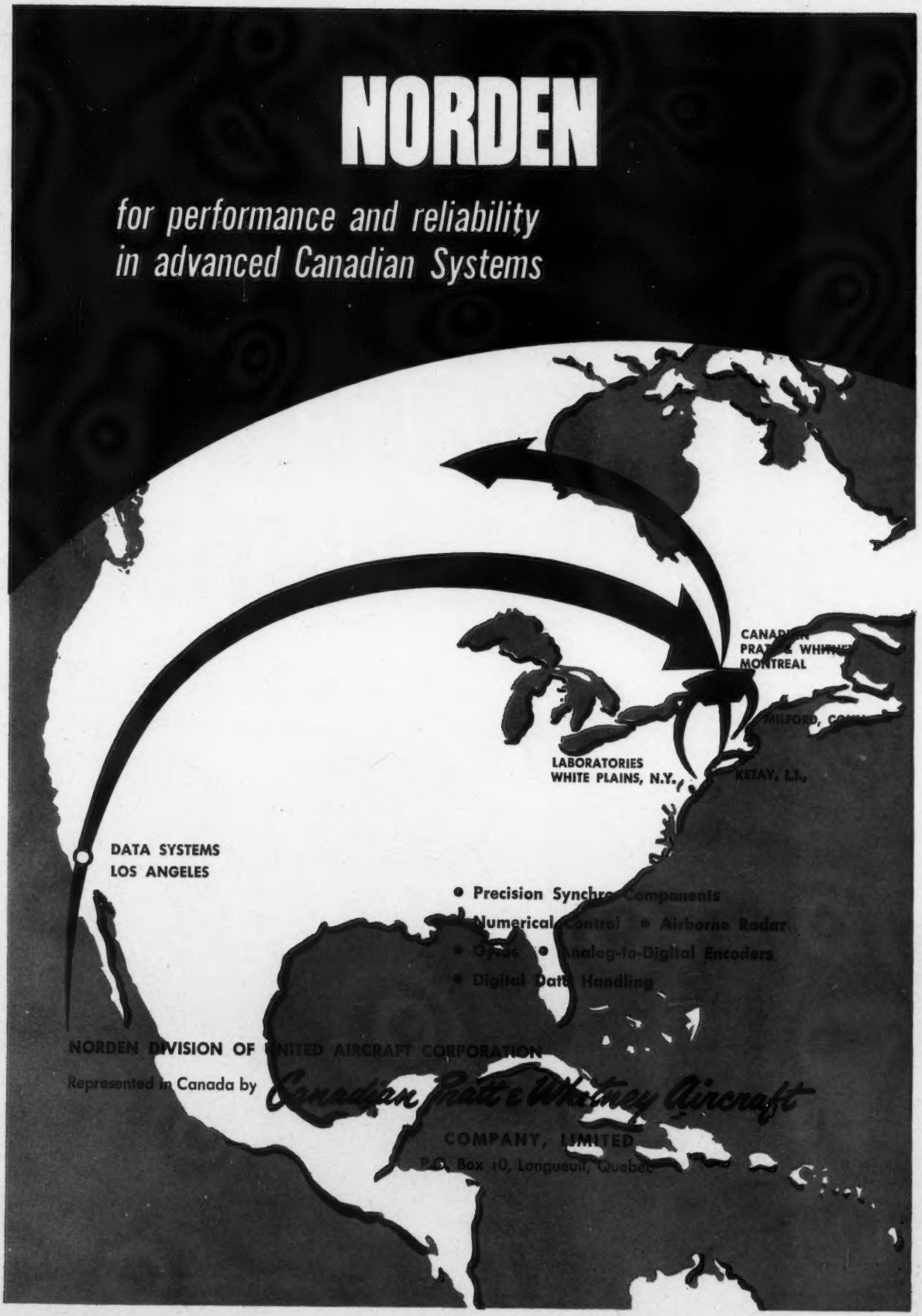


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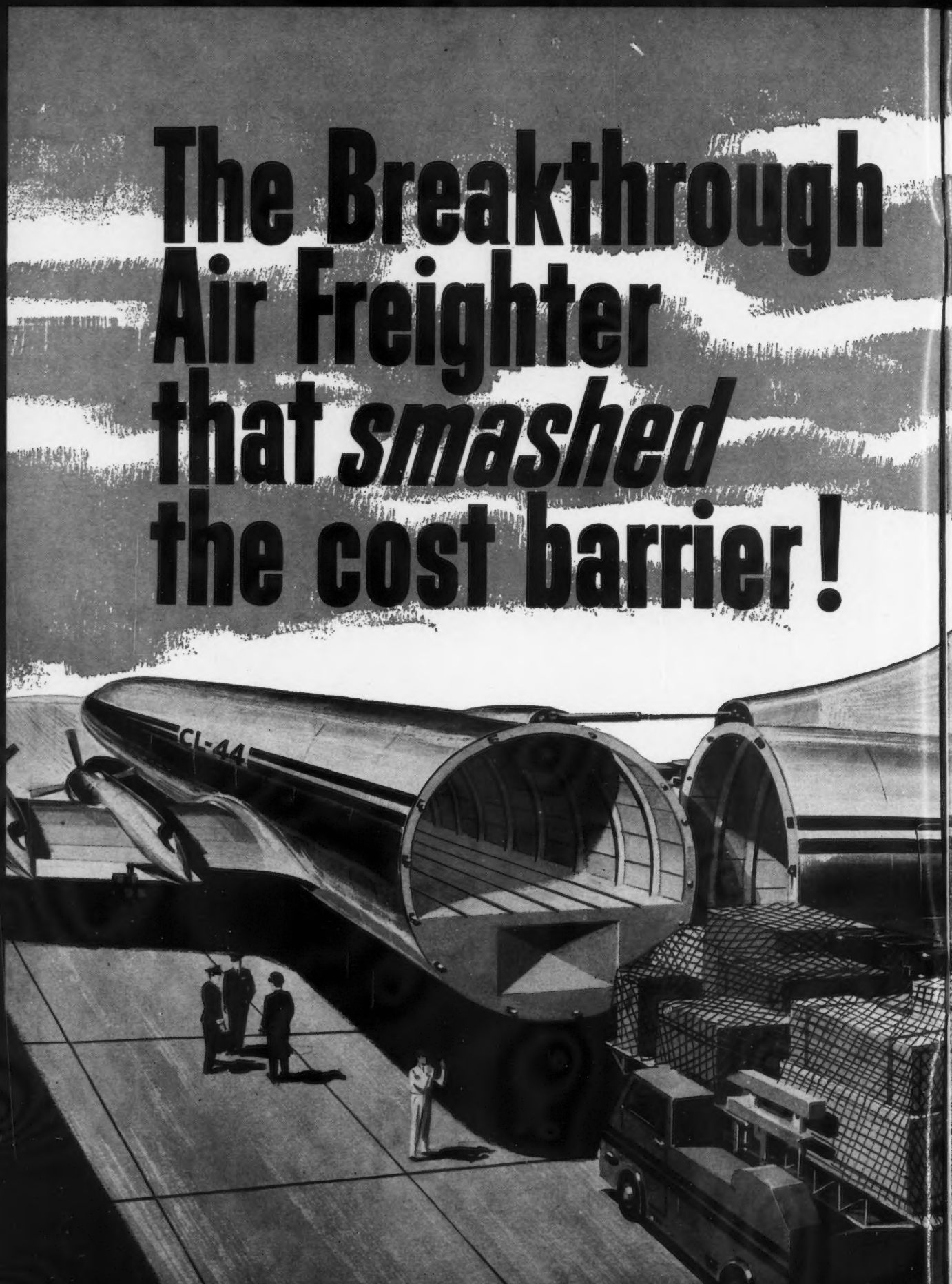
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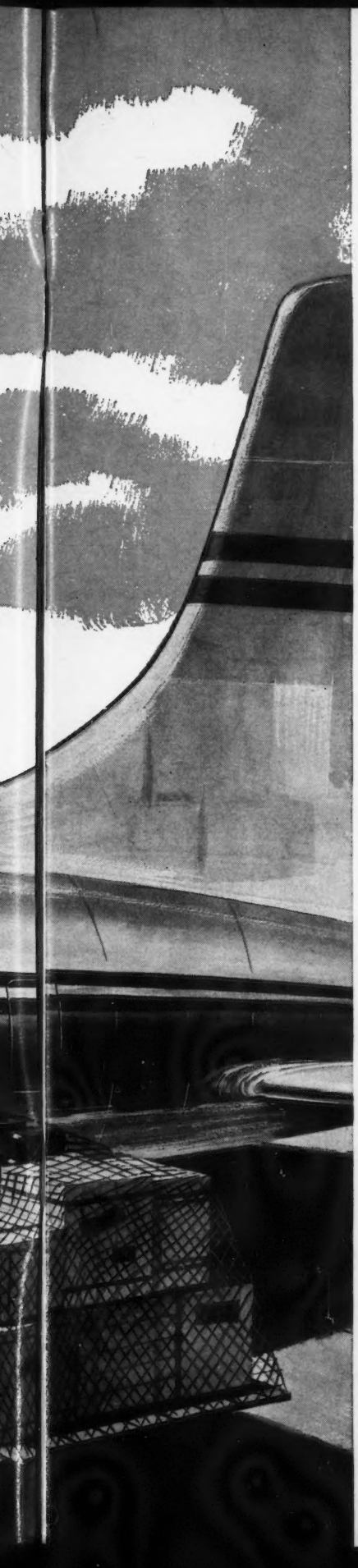

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- Span—142 ft. • Length—138 ft. • Cabin length—98 ft.
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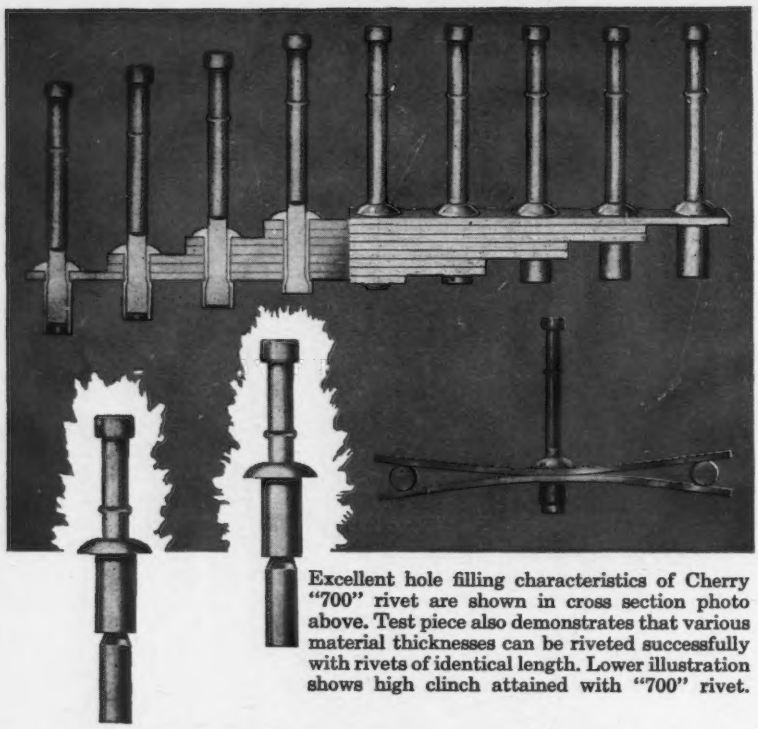

Excellent hole filling characteristics of Cherry "700" rivet are shown in cross section photo above. Test piece also demonstrates that various material thicknesses can be riveted successfully with rivets of identical length. Lower illustration shows high clinch attained with "700" rivet.

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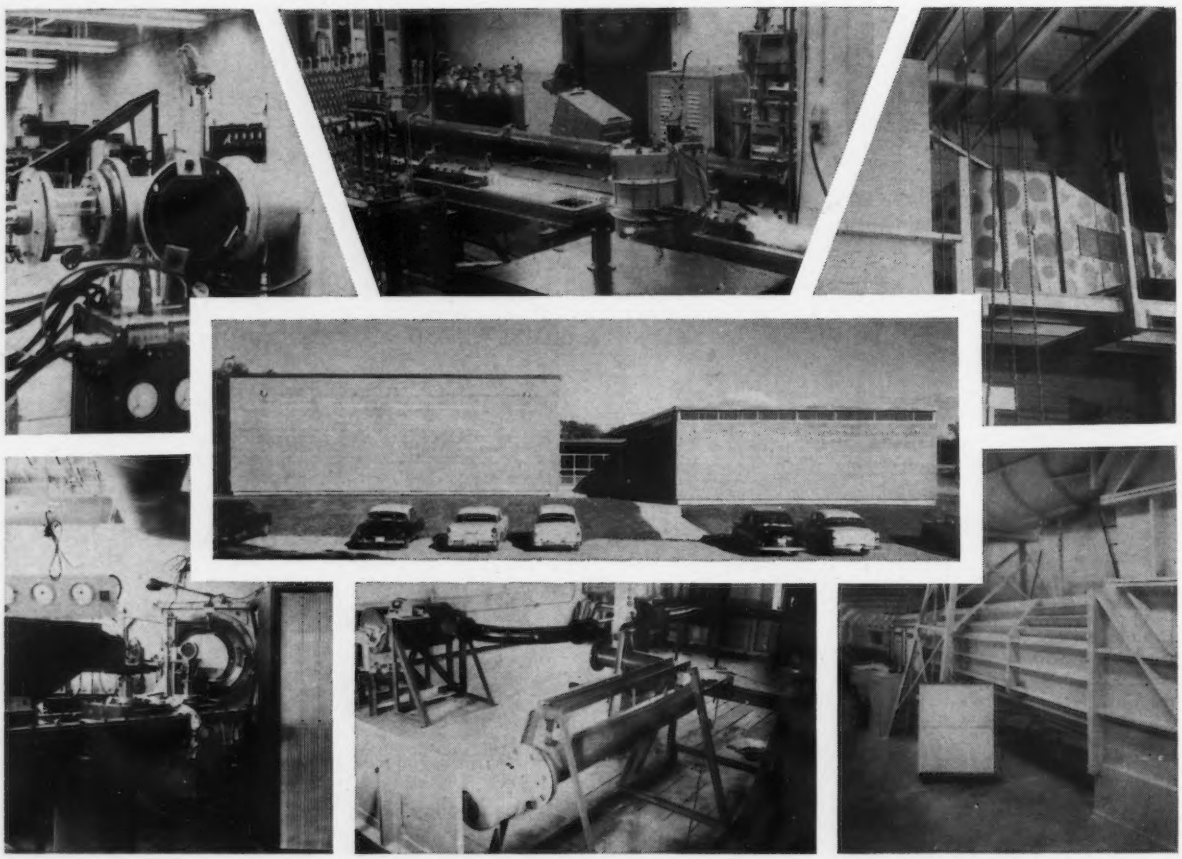


Plasma tunnel | Shock tube | Flow noise duct

Supersonic tunnel | Ground cushion research laboratory | Low speed tunnel

**The Institute of Aerophysics is celebrating the tenth anniversary of its foundation this year, and a new building in North Toronto is to be opened on the 16th October by Dr. A. H. Zimmerman, Chairman of Defence Research Board. The above photographs show the new building and a few of the research facilities of the Institute.**

# EDITORIAL

## THE ANGLO-AMERICAN AERONAUTICAL CONFERENCE

THIS year for the first time, the Canadian Aeronautical Institute is participating in the Anglo-American Aeronautical Conference, not as a full partner – we can hardly aspire to that yet – but rather as a son being introduced to his father's business. It might be timely to say something about this important series of international meetings in which, in due course, the CAI must play a proper part.

The First Conference was held in London in 1947, when the Royal Aeronautical Society played host to the Institute of the Aeronautical Sciences. Those of us who were there will remember it as a very friendly gathering; many of the delegates had worked together on common problems during the war and seemed hopeful that, through these Conferences, they would perpetuate, in times of peace, the exchange of ideas that had proved so valuable between allies. However, there was an air of unreadiness about it; neither the British nor the Americans had fully oriented themselves from wartime programmes to the affairs of peace; a change was taking place and nobody had completed any extensive work that he was ready to talk about.

Since 1947 the Conference has taken place every two years, first on one side of the Atlantic, then on the other. The Fifth Conference was held in 1955 in Los Angeles and the Sixth in Folkestone in 1957. The CAI was founded in 1954 and members of the CAI attended both of the last two Conferences, but as members of the RAeS or IAS, rather than as CAI delegates.

At Folkestone there was a meeting of members of the RAeS and IAS Councils, at which the possibilities of CAI participation in future Conferences were considered. As a result, the Presidents of these two societies wrote to the President of the CAI formally inviting Canadian participation in the Seventh Anglo-American Conference in 1959.

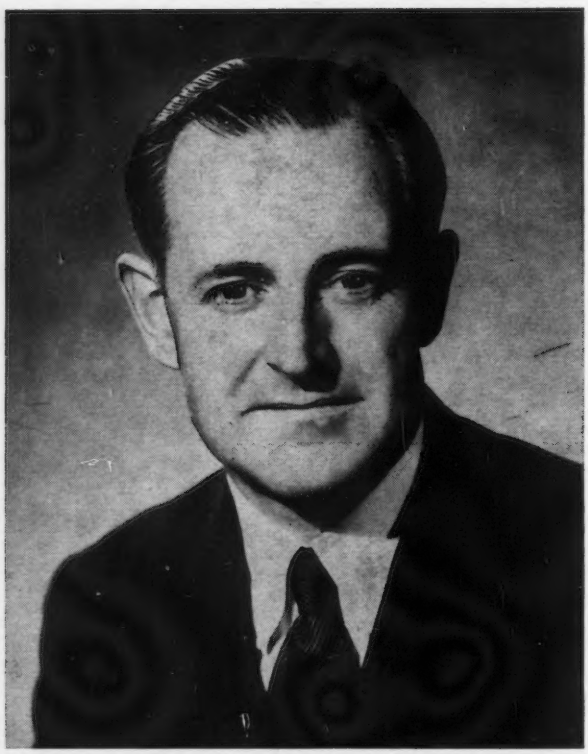
It was agreed that members of the CAI should be allowed to attend, as such, without necessarily being members of the RAeS or IAS as well. It was also decided that, at this Seventh Conference, to be held in New York, the programme should include two Canadian papers and a visit to Canada. At the time when these suggestions were made the Arrow project was in full swing and it seemed natural that the visit to Canada should be centred on Toronto. All this was an excellent introduction of Canadian contributions to this leading aeronautical conference in the English-speaking world.

The Arrow and the Iroquois, our two prize showpieces of research and development, have gone and we go into the Conference a trifle bloody; but still unbowed. We still have some first rate wares to display, although, like the delegates to the First Conference, we find ourselves in a state of change and perhaps unready to talk about very much.

And, speaking of a state of change, it is interesting to remember that when the last Conference was held in September 1957, we had not embarked upon the "Space Age". (Ominously Sputnik went up on the day of the unveiling of the Arrow, the 4th October, 1957.) Unless the rate of orientation increases with the rate of progress, the air of unreadiness, apparent at the First Conference, is liable to haunt us again – British, American and Canadian alike.

In any event the CAI is privileged to take part in the Conference and, in the Golden Anniversary of Flight in Canada, to welcome the delegates from the RAeS and IAS to our home ground.

# W. RUPERT TURNBULL LECTURER



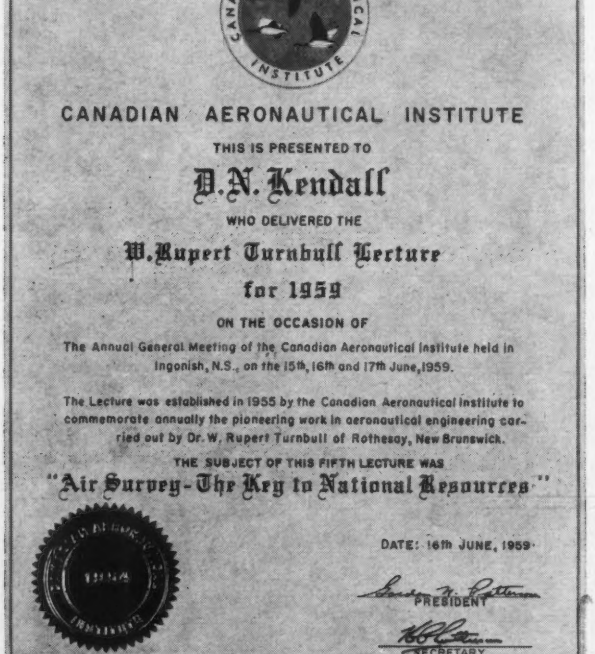
Mr. D. N. Kendall

***Mr. D. N. Kendall, President of the Photographic Survey Corporation and its associated companies, delivered the fifth W. Rupert Turnbull Lecture on the 16th June, 1959, at Ingonish, Nova Scotia. His lecture is reproduced on the following pages.***

Mr. Kendall was born in Oporto in 1914. He was educated at Ampleforth College and Oxford University. Before the war he was with the Aircraft Operating Company Ltd., Johannesburg. He served with the RAF from 1939 to 1945 and, for his work as Chief Technical Officer of the Allied Central Interpretation Unit, he was awarded the OBE and the US Legion of Merit. He joined Hunting Aerosurveys Ltd. and came to Canada in 1946 to establish the Photographic Survey Corporation, which has since expanded into several companies, all subsidiaries of Hunting Associates Ltd.; Mr. Kendall is President of each of them and Vice-President of Hunting Associates.

During the war he established a reputation as an outstanding authority on Photo Reconnaissance and his subsequent work in the development of Air Survey in Canada has received world-wide recognition.

Mr. Kendall is a member of the Canadian Institute of Surveying, the American Society of Photogrammetry and the Royal Geographical Society. He is an Associate Fellow of the CAI.



CANADIAN AERONAUTICAL INSTITUTE

THIS IS PRESENTED TO

D.N. Kendall

WHO DELIVERED THE

W. Rupert Turnbull Lecture

for 1959

ON THE OCCASION OF

The Annual General Meeting of the Canadian Aeronautical Institute held in Ingonish, N.S., on the 15th, 16th and 17th June, 1959.

The Lecture was established in 1955 by the Canadian Aeronautical Institute to commemorate annually the pioneering work in aeronautical engineering carried out by Dr. W. Rupert Turnbull of Rothesay, New Brunswick.

THE SUBJECT OF THIS FIFTH LECTURE WAS

"Air Survey-The Key to National Resources"

DATE: 16th JUNE, 1959

PRESIDENT

SECRETARY

# AIR SURVEY — THE KEY TO NATURAL RESOURCES†

**by D. N. Kendall***

***The Photographic Survey Corporation Limited***

## INTRODUCTION

It has been said recently by one of our Cabinet Ministers that Canada today leads the world in air survey techniques. It is an interesting observation but one which obviously needs critical examination. Perhaps the right place to draw any conclusions on the subject is at the end of this paper.

The term air survey needs some definition. It can be broadened to include all sorts of visual reconnaissances from counting caribou to studying smoke haze, or it can be narrowed to the stricter sense where something is measured instrumentally. I am taking the narrower sense and including in the subject only the following:

(1) Air photography to survey specifications.

(2) Photogrammetry, or the science of mapping from air photographs.

(3) Geodetic and control establishment, or the establishment of one's position on the ground in terms of latitude and longitude.

(4) The location and measurement of natural resources using special airborne instruments including those of a geophysical type.

## THE AIR PHOTOGRAPH

The most basic tool in all air survey is the air photograph itself. This is, therefore, my starting point. The air photograph has an immediate importance since it records factually everything visible in relation to its specification at the instant of exposure. Subsequent air photographs of the same area will show the changes which have occurred in the interval, again factually. Skill is, of course, needed in the interpretation of the air photograph to extract the maximum information. For instance a forester experienced in photographic interpretation can type a forest, establish the rate of regeneration and make deductions on maturity and pathological condition. A geologist can interpret geological structure, or tectonics, and very often name the rock type. He can certainly extrapolate on the air photographs from known rock occurrences into the unknown surrounding areas. Just so, a soil surveyor can establish soil type perimeters and often name the soil itself, while a civil engineer with a background of geomorphology and photo-interpretation can locate sand, gravel and other subsurface features by a detailed study of drainage patterns.

However these things cannot be done with any air photograph. To achieve any particular purpose obviously a minimum specification must be met. While the specification must take into consideration filters, sun angle, season and numerous other factors, in practice two items are of paramount importance from the interpretative point of view, i.e. scale and resolution.

Scale and resolution are interwoven as the combination of the two determines the minimum size of object which can be seen on an air photograph and thus what can be interpreted. Resolution is affected by the following:

(a) Ground speed. This is increasingly unimportant as shutters speed up.

(b) Aircraft vibration. This can be minimized by studying the vibration wave lengths in different parts of the aircraft and designing suitable mounts. Some aircraft are surprisingly better than others from a vibration point of view.

(c) Film grain and processing techniques. There have been great strides since the war in this area. Films are now faster and yet of finer grain. Greater speed of film permits, of course, faster shutters and the use of smaller lens apertures, so that gains come from several directions.

(d) Lens quality. The improvement in lens quality since the war, notably in Switzerland by the Wild Company, is remarkable.

The consequence of all these factors of improvement is that whereas in 1945 a photograph from 10,000 ft would enable an object 8 ft in diameter to be seen and normally identified, today from the same height we could identify an object 3 ft in diameter.

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†The W. Rupert Turnbull Lecture for 1959 presented at the Annual General Meeting of the C.A.I. in Ingonish, N.S., on the 16th June, 1959.

*President

In these days of supersonic aircraft an improvement by a factor of only 2.6 in 14 years may not seem significant. In practice it is very great indeed. It means that the aircraft can photograph from 2.6 times as high today, compared with 1945, and still get the same information. However since it is area coverage with which we are concerned, the number of photographs to be secured reduces by the square of the improvement in height, i.e. by a factor of 7. Since, to project the subject further, the cost of interpreting the photographs and mapping from them is largely a factor of the number of photographs which have to be handled, major economies result in every step of the compilation process, if a reduction of photographic scales through higher altitude photography can in fact be achieved through better resolution.

To relate this to economics, in 1946 the standard cost for obtaining photography at a scale of 1/15,000 was about $10.00 per square mile. Since then costs of materials and staff have at least doubled, yet the same information can be secured today for about $3.00 per square mile. For this development we must largely thank Swiss engineers, although others have also contributed significantly.

**PHOTOGRAMMETRY**

So far we have considered the air photograph solely from its resolution and interpretability point of view. However the air photograph is much more than this. It conforms to precise mathematical laws and thus can be used to make measurements, this science being known as photogrammetry.

For all practical purposes a lens can be considered as a pinpoint source of light at a definite distance, the focal length, from the focal plane of the camera, where the negative is located. Thus by similar triangles it can be seen (Figure 1) that $\frac{a}{f} = \frac{A}{H}$, where $a$ is the size of the negative, $f$ the focal length, $A$ the ground photographed and $H$ the height of the aircraft above ground. The scale of the photograph is obviously $a/A$ or alternatively $f/H$, which it equals. Thus an aircraft flying at 20,000 ft with a camera with a focal length of 6 ins, i.e. 0.5 ft, will produce photography at a scale of 0.5/20,000 or 1/40,000.

Unfortunately, however, the problem is complicated somewhat by the fact that the ground being photographed is not normally flat. In other words part of the ground will be nearer to the aircraft and will thus photograph at a larger scale than the lower ground. The resulting photograph varies, therefore, in scale according to the nature of the ground. It still, however, obeys geometric laws, which can be turned to advantage.

Clearly the point immediately below the aircraft, assuming the camera to be level, will record in the camera as the centre point of the photograph. All other detail will be radial from the centre point, displaced outwards if the ground is higher than the centre point, or inwards radially if lower.

Vertical air photographs are normally taken with a 60% fore and aft overlap. Thus the terrain being photographed is covered by at least two adjacent exposures. This means that there are two points immediately below the aircraft which are in their correct plan positions,

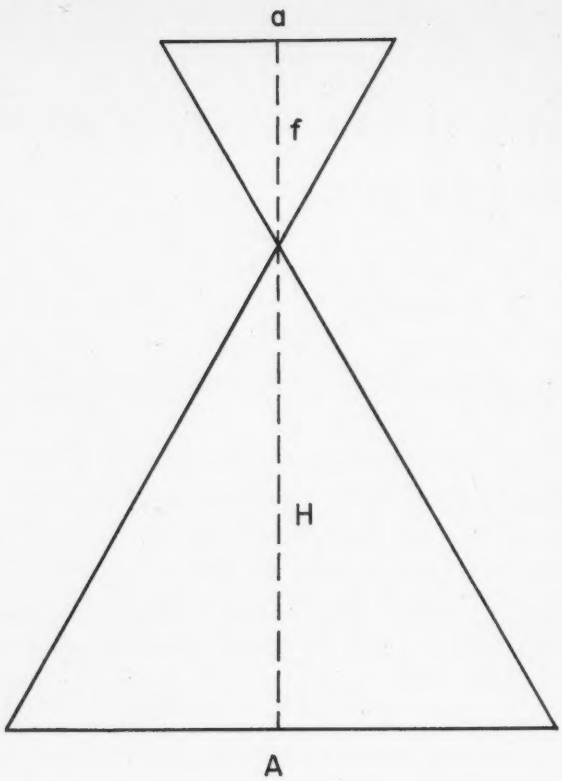


**Figure 1**

with the other detail being radial from them. It is possible, therefore, in theory to establish the true plan position of any point on a photograph by plotting the point of intersection of the radial lines leading to it from the centre points of two successive photographs. I say in theory, because in practice errors creep in, caused for instance by the fact that the camera is seldom exactly level at the time of the photograph, so that the point immediately below the aircraft is then no longer the exact centre point of the photograph.

**Photogrammetric instruments**

Obviously there is a mathematical relationship between the true plan position of any point of detail and the extent of its displacement. Simple trigonometry shows this. Thus if the exact amount of this displacement can be measured then the height of the displaced ground can be computed. Certain photogrammetric instruments, of a category known as Stereo Comparators, do exactly this. The most recent and sophisticated ones, costing about $60,000 each, will measure these displacements to one micron, recording the data automatically onto cards for feeding into computers.

The use of comparators for extracting measurements from air photographs is not new and was in wide use pre-war. However during the war years a mechanical method for adjusting the points became common practice. This method, known as slotted template, enables a whole block of territory to be adjusted simultaneously.

The photograph is replaced with a piece of card; the centre point is punched and a stud which fits the round hole exactly is inserted; for each of the other points to be fixed a slot some two inches long is punched out of the card and a stud is inserted which is the exact diameter of the slot; since each point will appear on at least two slots, by putting one card on top of the next the stud will slide up the slots until it occupies the position where it is radial from both centre points; the template system can then be expanded or contracted with the studs all sliding, but since all triangles are similar, expansion or contraction merely changes the scale of the whole assembly; it is only necessary, therefore, to know the true position of a few of the points in order to fix the scale of the whole assembly. The studs are hollow and once scale is fixed a pointer can be inserted to pinprick the exact position of the point being established.

This slotted template method was introduced into Canada in 1946 for the first time and was used extensively for the next few years. The method is quick and inexpensive but has accuracy limitations. Also it is normally only applicable where planimetric detail only, i.e. no contours, is required. However it served its purpose well. This method was a US development.

There are few people today who are not aware of the principles of stereoscopy and who have not viewed air photographs in relief under the stereoscope. It will therefore suffice to say that if the ground is photographed vertically from the air from two positions, normally with a common overlap of 60%, the common area can be viewed in the third dimension. This gives promise of a means for obtaining contours from the photographs. Prewar this was done very crudely by establishing on the ground with a barometer the height of the top of a hill and the height of a point in an adjacent valley. The photogrammetrist then visually, and rather arbitrarily, divided off the intervening slope into the points where he thought the successive contours would lie. He then proceeded to contour the whole terrain visually on the photograph. Needless to say the method was highly inaccurate.

About 1936 the Germans and the Swiss began producing some highly accurate photogrammetric instruments which enabled contour precision to be increased enormously. They were not the first such instruments, as various types had evolved in the 1920's, but 1936 marked the beginning of their acceptance and a new era in precision (Figure 2).

These plotting instruments incorporated three important features. First – they enabled the two overlapping photographs to be mounted in the instruments in such a way that any tilts in the photographs at the time of exposure could be reset, so that an exact replica of the ground as a three dimensional model could be viewed. This removed one of the prime sources of error, as most methods previously had to assume that the photographs were level. Second – they incorporated correction plates which compensated for the fact that no camera lens at that time was truly symmetrical. True symmetry is a very recent development with the Swiss Aviogon lens. Third – they enabled a small dot or floating mark to be superimposed on the photographic model which could

**Figure 2**
**Wild A-7 first order photogrammetric mapping instrument. This is used for air triangulation and contouring where accuracies are required.**

be moved freely across it and which corresponded to the point of a pencil, to which it was geared, thus enabling a map to be drawn. The operator now merely had to make the dot follow the detail on the air photograph which he wished to map.

The basic principle of this floating mark can be explained quite simply. If two dots are viewed, one by each eye, they will be *seen* as a single dot at the point where the lines from the two eyes through the two dots meet. If the two dots are moved closer together the effect is to raise the single dot seen. If, therefore, the separation of the two dots can be carefully controlled and measured it then becomes possible to establish the dot at any given level and to raise or lower it through any desired distance. Should it then be desired to draw, for instance, the 100 ft contour, the dot can be set at this level $z$ and moved only in the $x$ and $y$ directions, with the operator keeping it as accurately as he can on the ground. The controlling factor in accuracy now becomes the precision of the human operator's eyes.

Today these photogrammetric plotting instruments are of many different types. According to accuracy they are known as first, second or third order instruments. A first order instrument will cost about $50,000 and can measure in plan or height with an accuracy of at least 1/5,000th of the flying height. In other words, if the air photograph is taken from 10,000 ft a measurement

accurate to within 2 ft can be made. If the photograph is from 2,500 ft, the accuracy should be 6 ins. The accuracy today is adequate for virtually all mapping and engineering purposes, including detailed earth computations. Within two years road contractors will be paid for earth moved almost exclusively from photogrammetric measurements, these being quicker, cheaper and more accurate than any other means.

These photogrammetric instruments are manufactured mainly in Switzerland, Germany, Italy and the USA. To a lesser extent France and the UK also produce. Canada has so far gone only to prototype stage on one instrument, this being a development by Canadian Applied Research Limited, based on an invention by Mr. S. C. Gamble, Director of Surveys for the Department of Mines and Technical Surveys, Ottawa.

## GROUND CONTROL

Photogrammetric mapping has little meaning, or accuracy, unless it can be tied to the ground in terms of latitude and longitude or some such reference. Maps can be made from air photographs but without control they cannot be scaled nor can accuracy appropriate to the map scale be maintained. It is possible to bridge or air triangulate from one photograph to another but errors accumulate and there is, therefore, a limit to the number of photographs which can be bridged without control.

In the past a reasonable distribution of the cost of mapping might have divided into 20% for the air photography, 40% for control and 40% for photogrammetric compilation. Today all this is in the melting pot.

Control can consist of knowing the exact position of certain points on the ground. It may be sufficient to have a point, say, every five photographs. The number of points depends on many factors too lengthy to cover here. It is, perhaps, sufficient to say that ground control has been in recent years revolutionized by two factors, first the helicopter which has speeded up enormously the ground movement problem and, second, the Tellurometer which is a radar point-to-point measurement instrument of very high precision. The Tellurometer was a South African development.

### Shoran control

Until recent years it was always assumed that control for photogrammetric purposes necessitated knowing the exact position of points on the ground. In fact the photographs would be just as effectively controlled if the exact position of the aircraft at the moment of exposure were known. Naturally the position immediately below the aircraft would then also be known. In practice this can be done by using radar positioning equipment such as Shoran. The basis of Shoran control is a number of stations on the ground equipped with radar operating on a wavelength of 10 cm. Normally some of these stations are located at known geodetic points, while others straddle the area to be controlled. The aircraft carries a mobile station which transmits to the ground stations and, in effect, measures the time required to transmit and receive back a signal. After adjusting the time thus measured to allow for variations in the speed of propagation, the distances from the aircraft to two or more ground stations can be established with an accuracy of about ±30 ft.

The first step in using Shoran lies in establishing the exact position of the various ground transmitting stations in relation to each other. This is done by flying, perhaps eight times, across the lines between stations. Obviously the minimum values secured on each run represent the line crossing point. The eight values are then meaned. Thereafter it is only necessary to record the values from two convenient stations at the instant of photography in order to provide control for the whole block of photography. Being UHF, line of sight is necessary between the aircraft and the ground stations, so that the latter have to be within 300 miles of each other.

Most of our control in the Northwest Territories and throughout the Arctic Islands has been established by Shoran, most of it by the RCAF, but part by civil air survey companies. Wing Commander Showler was awarded the McKee Trophy last year for his part in directing the RCAF's Shoran operations.

The Shoran approach to the provision of control is quite expensive and normally only justified for remote regions where ground access is difficult or hazardous. The recent Tellurometer developments with the helicopter as the transportation vehicle probably means that Shoran will be used much less in the future on straight economic grounds. Shoran was a US wartime development.

### Airborne Profile Recorder

A few years ago Dr. Lyle Trorey, a well-known Canadian photogrammetrist, suggested another and somewhat novel approach to the provision of control. He pointed out what every school boy knows, namely that an isosceles triangle is fully solved if the angles are known plus the length of the perpendicular from the apex to the opposite side. This condition can be repeated in an aircraft since obviously we know the camera angle, and thus all angles, assuming that the camera is level. All we need to know, therefore, is the exact distance from the aircraft to the ground. This, fortunately, we can secure thanks to a development known as the Airborne Profile Recorder (APR) which will give this information to an accuracy of about ± 10 ft.

The APR was originally conceived by Mr. Bruce Waugh of the then Department of Mines and Resources in Ottawa. He persuaded the NRC to produce a somewhat crude prototype. The full development of the invention was taken up by The Photographic Survey Corporation Limited in Toronto, using the facilities of what is now Canadian Applied Research Limited. Today's instrument, the Mark 5, represents twelve years of continued development at very high cost.

The APR consists of a 3 cm radar which directs a very narrow beam vertically downwards by means of a parabolic dish of 48 ins diameter carried under the aircraft. The readings are continuous so that not only is the distance from the aircraft to the ground measured but the continuous record provides a profile of the ground. The latter is not, of course, a true profile because the aircraft itself changes height, so that compensation has to be made before a true ground profile is secured. This aspect in turn involved invention and development.

The only datum available at height is, of course, pressure. This appears to be fairly stable at certain heights once ground effects are left behind. The pressure datum does, however, vary with wind direction and velocity, but formulas can be used to adjust the datum to a common level, provided that wind velocities and directions are recorded throughout the flight.

Having found, therefore, that it is possible to establish an absolute pressure datum after suitable adjustment the main problem that remains is to devise an instrument of the statescope type to record the deviations of the aircraft from the datum. Such an instrument must be able quickly to detect changes of one or two feet in the aircraft altitude. For inertial reasons any bellows aneroid method would not suffice.

The problem was solved by inventing an instrument named the Hypsometer. This uses the principles that a liquid boils at different temperatures with pressure and that modern Thermisters can measure slight temperature changes with the required precision. Tests on the Hypsometer show a performance which is linear from ground level to 60,000 ft, unlike bellows systems which drop off badly at height.

The APR is now in wide use in a number of countries and has been purchased in fair quantities by the USAF. All sales and manufacturing rights to this instrument have been acquired by Canadian Applied Research Limited. Needless to say this is a Canadian development. Its importance lies not only in control for mapping, but also because the profile information can be used for the vertical control required for contour mapping. The NRC in Ottawa using APR data for control have achieved remarkable and unprecedented accuracies on bridging long distances photogrammetrically. Their techniques have yet to be applied widely but it appears that a major new mapping tool has been developed which is not only effective but inexpensive.

#### FUTURE TRENDS IN PHOTOGRAMMETRY

Before leaving the subject of photogrammetry, certain new developments and trends need mentioning. These are three in number.

The first relates to bridging or air triangulation. Obviously if better bridging methods could be devised less control would be needed for mapping and the costs could be further reduced. Success along these lines looks possible by better use of computers. Already attachments to the first order plotting instruments exist which record onto punched cards the co-ordinate information collected in the bridging process. Computers provide the opportunity, with the right programme, for analyzing this data more thoroughly than before and thus adjusting the bridging more accurately.

The second relates to the combination of photogrammetry and computers to solve engineering problems. In the last two years it has become quite common practice in connection with highway design to take off by photogrammetry cross-sections at, say, 50 ft intervals across proposed highway routes. These profiles are fed direct onto punched cards from the photogrammetric instrument. The cards are then put through a computer which selects the most economical highway template and balances all earth work. Since the computer can test all possibilities the cheapest route should emerge.

The third development appears to be the most major of all. Ever since the war the US Corps of Engineers have recognized that the bottleneck in mapping remains the operator who has to keep the floating mark on the ground and move it along the detail to be mapped. They have felt that there should be some method for doing this automatically, or at least semi-automatically. During the last eight years they have awarded a number of development contracts to electronic firms running into large sums aimed at achieving a solution. So far their expenditures have been in vain. Meanwhile, however, investigation of the problem was one of the projects assigned to the Research and Development Division of Hunting Associates Limited, the parent company of the Photographic Survey Corporation Limited. A year ago they achieved a theoretical solution which has now been proven. The results are very promising not only in speeding up mapping by a factor of several times, but also in producing an accuracy higher and more consistent than is possible with a human. Fortunately the human will still be needed to monitor the machine (Figure 3).

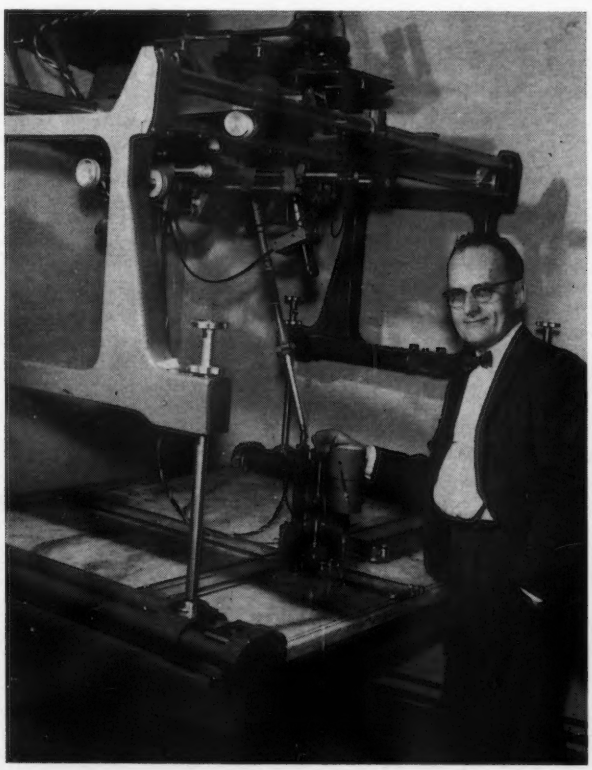

**Figure 3**

**The Stereomat, with its inventor Mr. G. Hobrough. This represents the first successful attempt anywhere to map automatically from air photographs.**

This new instrument, which has been given the trade name of Stereomat, operates on the principle of signal correlation. The two stereoscopic air photographs are each scanned by means of a cathode ray tube employing a random scan. The signals from the two photographs are analyzed to compute parallax. The floating mark is then brought to ground level which is the point where there is zero parallax. To contour it is only necessary to freeze the $z$ servo, in which case the $x$ and $y$ servos will follow round the side of the hill. To profile, which is the main interest of the US Corps of Engineers, the $z$ servo is left free while profiles at fixed intervals are recorded, usually by digital read-out onto magnetic tape, by setting the $x$ and $y$ servos to follow predetermined paths. The contours can then be extracted at will from the tape at any desired contour interval, scale or projection.

The US requirements from such an instrument are quite high and units have now been ordered for evaluation by two branches of the US forces. The initial unit will come from Canada but it has been necessary to arrange for subsequent production to take place in the USA under licence.

This is again a Canadian development and one which is likely to have considerable impact over the coming years.

#### DEMAND FOR MAPS

Much time has been devoted so far in this paper to the subject of mapping. Today virtually all basic mapping by governments employs photogrammetric methods. The same trend has occurred in most engineering fields, such as highways. The map, however, is not really an end in itself. Maps are important for many reasons; in fact without adequate maps the whole development of a nation is seriously handicapped. Their greatest use undoubtedly derives from the fact that they provide the base upon which to record data, principally natural resources information. Production of geology without a base map upon which to compile it is inconceivable.

In Canada, in spite of prodigious efforts over generations, mapping of the country is woefully inadequate. This has been ably demonstrated before a Parliamentary Committee recently by the Department of Mines and Technical Surveys. At present rates of production it will be at least fifty years before Canada is adequately mapped. World-wide not more than 5% of the earth's surface has adequate maps. The task should be accelerated as map production has a long lead time and it is too late to demand the maps when they are needed. Unfortunately acceleration requires, like everything else, more funds.

This is not to imply that the present survey efforts in Canada are small. Probably in relation to population they exceed any other nation. But then the country is larger and the backlog greater than elsewhere. To give some idea of the extent of effort, at least 40 civil aircraft plus 20 helicopters are exclusively engaged across Canada on survey operations. This does not include any military aircraft. In Canada six large firms work in this area, as well as five smaller firms. This compares with over 60 substantial firms in the USA, where the expenditure on surveys by industry and government, almost exclusively using air methods, now exceeds $200,000,000 annually.

Curiously enough, in spite of the large requirement, improvements in methods and cost reduction has meant that the capacity of the air survey industry has expanded faster than the funded demand. In consequence the industry in both Canada and the USA has found itself short of work. It is to be hoped that this is a temporary situation.

#### NATURAL RESOURCES

The wealth of a nation is very closely tied to the wealth of its proven natural resources, whether soils, forests, water or minerals. An ore body has no value until it is located, measured and proven to be economical. However once so measured it becomes part of the capital of the nation. It becomes an asset against which the nation can borrow or arrange credit. Developed the natural resource provides employment and the basis for secondary industry.

The cost of locating and measuring natural resources is, of course, high. However, normally it represents only a small percentage of the capital value of the resources located and thus added to the national wealth. On pure policy grounds it would appear, therefore, that every nation, developed or undeveloped, should devote its maximum possible effort to the proper inventorying of its natural resources.

I have already made the case that the first step in tabulating natural resources is to have a map upon which to record them. I have covered some of the steps in the evolution of the basic mapping techniques during recent years, which put map production, cost and time-wise, within reach. I should now cover some of the airborne developments which enable the resources themselves to be located once the maps exist. In practice these developments are mainly in the geophysical fields and thus confined to mineral location, although specialized photography, such as infra-red and colour, has helped in soil and forest typing.

As a generalization it might be said that most of the major ore bodies in the world which outcrop have been located. Today there are few parts of the world where man has not trodden, unless it be some inaccessible spot unlikely to be economical for ore extraction.

However only about 5% of the earth's surface actually outcrops. The rest is covered by vegetation or soils. It is logical, therefore, to suppose that no more than 5% of the earth's minerals have yet been found, but what is left remains hidden.

Going back to the turn of the century, the oil industry made its finds because oil seeps showed at the surface. These indications, however, soon ran out and a tool had to be found to learn about the subsurface which was cheaper than drilling blindly. The solution was sought in geophysics, mainly seismics. Today the mining industry is in much the same position as the oil industry

fifty years ago. The future ore bodies upon which they must depend will largely be those just below the surface and presently hidden from us. The tools for their location have to be geophysical.

Mining geophysics has been practiced for years on the ground. Its application was, however, necessarily specialized and restricted because of its high cost. $600 per square mile was not unusual and one mining company once spent $150,000 on geophysical survey of three square miles.

#### Airborne Magnetometers

During the war years for the first time an effective airborne geophysical tool was developed. This was an airborne Magnetometer which measured the small changes in the earth's magnetic field caused by the varying quantities of magnetite, i.e. iron, in the underlying rocks. The steel in a submarine has the same effect and was the reason for the wartime development. This type of instrument, known as MAD gear, is still in use by anti-submarine search aircraft.

The original airborne Magnetometers were developed in parallel by the Gulf Oil Company in the USA and by the Bell Telephone Company on behalf of the US Navy. Both followed the system of employing three mutually normal fluxgate coils, one for recording and two for azimuth. When the recording coil is aligned exactly along the total magnetic field the other two coils are automatically at right angles to the field and therefore recording zero field. Any misalignment immediately introduces a field into the orienting coils, which then actuate servos to bring themselves back to zero, thus realigning the measuring coil. The total magnetic field varies from about 30,000 gamma at the equator to about 60,000 gamma at the poles. The airborne Magnetometer will record the total field to an accuracy of one gamma. Such accuracies are necessary since a 5 gamma anomaly may be of significance in oil exploration.

Following the war years the Gulf Magnetometer was perfected as a geophysical, as opposed to submarine detection, tool, this being done by the Gulf Oil Company's Research Division. At the same time in Canada, The Photographic Survey Corporation Limited took on the redesign for geophysical purposes of the US Navy instrument originally developed by the Bell Laboratories. Patents did not issue until 1950 when those of Bell and Gulf were found to be in conflict. The matter was settled amicably under an arrangement whereby Gulf granted a world licence to The Photographic Survey Corporation Limited, who in turn recognized Gulf's prior position.

The airborne Magnetometer is now in very wide use all over the world. It costs from $4 to $10 per line mile to operate, including data reduction. Spacing between flight lines is usually ¼ mile, so that per square mile costs might be on an average $25. This compares with at least $150 on the ground. As a consequence it is used in a reconnaissance exploration role to cover wide areas. Probably 300,000 line miles of magnetics are flown in Canada alone each year.

Since the war Gulf Research in Pittsburgh have continued to improve their airborne Magnetometers to build in greater reliability with less weight. Meanwhile, also in the USA, a new type of Magnetometer, known as the Varian, has been developed in recent years using the principle of nuclear precession. This has good applications, the only problem being that recording is not continuous, the spacing between measurements being of the order of one second. This equipment has been licenced to Spartan Air Services Limited in Canada.

Airborne Magnetometer readings from any instrument are normally recorded as a continuous profile, the variations in the profile being fluctuations in the total field caused by the changing magnetite content of the rocks below. By plotting these profiles, just as if they were topographic profiles, it is possible to produce a contoured map, the contours being at perhaps 10 gamma or 25 gamma intervals. The contours will then outline geological features of many types, whether or not they appear on the surface. Iron formation in particular is easily identified as it normally produces large sharp anomalies.

Airborne magnetics have been widely used by all of the main iron mining companies in Canada, either to find new ore bodies, as at Marmora, Ontario, or to extend known mineralization, as in Labrador. Marmora is an interesting example since the ore body lay beneath 200 ft of limestone without any surface indication.

#### Airborne Radioactivity Counter

The next type of airborne geophysical tool to be developed was the airborne Radioactivity Counter. At first batteries of Geiger Counters were used but proved ineffective. The break-through came at the University of Manitoba with the development of an airborne Scintillation Counter, based on the use of a large sodium iodide crystal. When bombarded by gamma rays emanating from surface rocks the crystal gives off ultra-violet light, which can be measured with a photo-cell. Unfortunately it only requires a small overburden of soil or water to shield the gamma rays so that the instrument has virtually no depth of penetration. Even so it can be useful and has been indirectly successful in finding some of our mines. The radioactivity record can be contoured for intensity as with the Magnetometer. Although today these instruments are built in the USA and UK as well as in Canada, the pioneering was here.

#### Electro-Magnetometer

The third type of airborne geophysical instrument is the Electro-Magnetometer. This uses the principle that an induced electro-magnetic field when passed over a conductor will induce a secondary field which can be measured if it is close enough. Since sulphides are good conductors and copper, lead and zinc are normally found in sulphide form, the method obviously has important applications.

Many attempts to design an airborne Electro-Magnetometer were made after the war, the first successful one being designed by International Nickel in the early 1950's. This was followed by Hunting Associates Limited in Toronto, who produced a system

**Figure 4**
**Helicopter-borne electromagnetic instrument for measuring both in phase and out of phase responses from conductive rocks.**

operating on two frequencies (Figure 4), one high and one low, in order to distinguish between good and poor conductors. Since then some five or six systems have been evolved, mostly in Canada.

The first big find by EM was the Heath Steele ore body in New Brunswick. This was found by the Inco equipment. Subsequently the Hunting dual frequency system was fortunate in helping to locate no less than eight major ore bodies, including Mattagami.

#### Scope of geophysical work

I have described very briefly the three main airborne geophysical tools. Each is important in itself. However, if the three types of information can be secured simultaneously, their value goes up enormously, since supplementary information is secured by the comparison of one type of data with another. Geology and geophysics are complicated subjects and there is always danger in oversimplification. However, at the risk of such oversimplification, the following generalizations hold:

(a) If an anomaly is magnetic but non-conductive and non-radioactive, the anomaly should be iron formation.

(b) If it is magnetic and conductive, it could be nickel.

(c) If it is only slightly magnetic but a good conductor it could be an interesting sulphide with copper, lead or zinc.

(d) If it is conductive but not magnetic it could be sulphides or graphite or just a sheer zone filled with salt water.

(e) If radioactive but non-magnetic it is worth investigating for radioactive occurrences.

(f) If magnetic and radioactive it is probably a carbonatite with thorium and rare earths, as at Oka on the Ottawa River.

Most geophysical work is carried out on behalf of mining and oil companies and consequently tends to remain confidential. For this reason it is difficult to collect over-all statistics. Enough, however, is known to be certain that a far greater volume of airborne geophysics is being carried out in Canada than in any other country, including the USA. For this reason operating techniques as well as instrumentation tend to have their development here (Figure 5). In the light of this the statement of our Cabinet Minister that Canada leads the world in air survey perhaps bears some truth.

To a considerable extent Canada's leading role in this field has been recognized abroad. Three of Canada's six air survey companies carry out foreign contracts. In the past five years they have worked in over 50 foreign countries. Surprisingly enough the annual volume of foreign contracts carried out by Canadian air survey firms is about equal to the combined foreign volume of all the US companies. Under the Colombo Plan Canada is also helping to speed up national development in South East Asia by contributing natural resources inventories. Typical have been the geological and soil mapping of Pakistan.

#### CONCLUSION

In conclusion, it is clear that we must develop our North on both economic and military grounds. Development without maps is inconceivable. Mapping produced by means other than airborne is equally inconceivable. Virtually the only potentially economic resource in the North is minerals and their location by means other than airborne is impractical and uneconomical. I must conclude, therefore, by quoting the title of this paper – "Air Survey – The Key to Natural Resources", and the key to the development of the North.

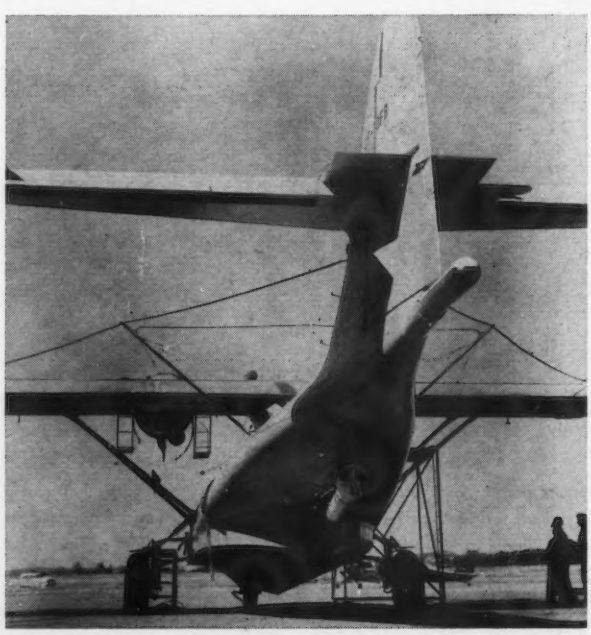

**Figure 5**
**Geophysical Canso equipped with dual frequency Electromagnetometer for measuring conductivity and Magnetometer for iron content of rocks. Note transmitting coil in bird below aircraft and Magnetometer at the tail.**

# PRESSURE DROP AND MIXING IN BURNERS†

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SUMMARY

On the assumption that burner performance is gas-mixing controlled, an attempt is made analytically to correlate dimensions, mass flows, temperatures, temperature and fuel/air distributions, velocities and pressure losses; the whole on the basis of rather sparse empirical data on the behaviour of single jets injected into an air stream. Some conclusions may be drawn, but more experimental data would be highly desirable.

## INTRODUCTION

It has long been felt that burner design and performance estimation is much more an art than a science. Empirical correlations are used by various companies, based on their particular series of burner designs. However, little is found in common among such correlations; this is due to the individual design idiosyncrasies built into the particular line of burners correlated.

Largely because none of these correlations is generally available, and partly because of the challenge involved, an attempt is made to apply fundamental concepts governing the processes in a burner to the analysis of this component. The sparseness of data on some of these processes, and their complexity when considered together, make it necessary to make numerous assumptions, justifiable only because they are necessary at this stage.

## LIST OF SYMBOLS

$A_L$ Cross sectional area of liner.

$D_j$ Diameter of round vena contracta of air jet.

$D_o$ Width of elliptical orifice such that: $D_j^2/D_o^2 = 0.60$

$d_L$ Characteristic depth of liner: equal to the depth of an annular liner, and equal to some fraction of the diameter of the individual cans in a cannular arrangement.

$F_h$ Penetration correction factor for cases $V_A \neq 0$.

$F_\theta$ Unmixedness correction factor for cases of $V_A \neq 0$.

$f/A$ Fuel/Air ratio: subscripts as for temperatures $T$.

$g$ Acceleration due to gravity.

$h$ Penetration, to the centroid of the jet flow.

$h'$ Penetration, to the peak of the jet flow property distribution.

$h_{max}$ Penetration, to the outer tangent to the jet flow property distribution.

$L$ Distance downstream of a jet orifice.

$P$ Total pressure: subscripts as for velocity $V$.

$p$ Static pressure: subscripts as for velocity $V$.

$\Delta P$ Loss in total pressure.

$q$ Dynamic head: subscripts as for velocity $V$.

$R = 96$ ft/°C Gas constant.

$Re_j = \frac{D_j}{\nu}\sqrt{V_y^2 + (V_L - V_A)^2}$ Characteristic mixing Reynolds number, controlling the intimacy of mixing.

$r_L$ Radius of liner centre line relative to the axis of the annulus.

$T_A = T_j$ Compressor delivery total temperature.

$T_L$ Total temperature of liner gases at point of jet injection.

$T_m$ Total temperature of liner gases after jet mixing.

$t$ Time from passage of a given particle through the jet orifice.

$V_A$ Velocity of air approaching jet, parallel to the liner.

$V_j$ Jet velocity at vena contracta.

$V_L$ Velocity of gas in the liner at point of injection.

$V_m$ Velocity of gas in the liner after jet mixing.

$V_y$ Component of jet velocity normal to the liner.

$W$ Weight flow: subscripts as for velocity $V$.

$\theta_c = \frac{T_m - T_{min}}{T_m - T_j}$ Unmixedness based on the peak of jet property distribution.

$= \frac{f/A_m - f/A_{min}}{f/A_m - f/A_j}$

$\theta_d = \frac{T_{max} - T_m}{T_m - T_j}$ Unmixedness based on the trough in jet property distribution.

$= \frac{f/A_{max} - f/A_m}{f/A_m - f/A_j}$

$\nu$ Effective kinematic viscosity of jet mixing.

$\alpha$ Indicates proportionality.

$\Delta$ Indicates an incremental quantity.

## BURNER OPERATION

A typical burner operates as follows. Fuel is sprayed into a stream of air. Almost simultaneously with the evaporation and mixing of the fuel, heat is added to the stream by mixing of the recirculation gases, or by heat transfer through a vaporizer wall. According to Reference 1, in the absence of boundaries, the cloud of droplets behaves as if droplets suddenly vanished in random

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fashion, leaving the size distribution unaltered. This is due to a combination of typical spray spectra with the characteristics of the evaporation process. Before evaporation is complete, burning starts and a third process begins – the admixture of additional air from the secondary jets. The initial, macroscopic mixing of these tends to quench the reactions by removing more heat than the air brought into molecular contact with the fuel can release. As the jets break down into smaller eddies, these become of dimensions comparable with the laminar diffusion lengths for the available residence times, and the heat release rapidly overtakes quenching.

Where the last eddies are completing their diffusion-combustion process, the dilution air intercepts the reaction and merely redistributes air and gases into a pattern acceptable to the turbine.

Chemical considerations have been left out of the picture because over a broad operating range the processes in a burner are believed to be governed by other than chemical parameters. The chemical reaction rate varies with composition, temperature and pressure in such a way that at altitude conditions it may become controlling, but the present paper deals with processes below this critical altitude. In passing, it may be mentioned that some carbon is released in most hydrocarbon flames, but it is rapidly consumed unless it is quenched by a solid

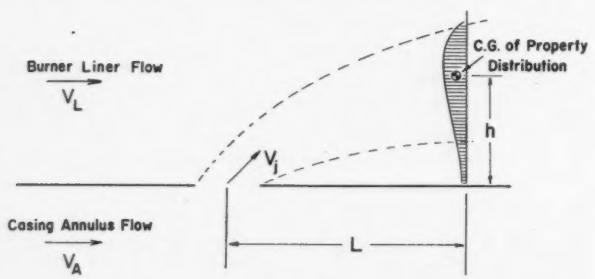


**Figure 1**
**Diagram of a typical jet mixing process**

surface on which it deposits; or by a cool jet of air which brings it below reaction temperature, in which case it causes smoke. Hard, flaky carbon deposits are formed by fuel impinging on surfaces hot enough to crack it, but not hot enough to support combustion.

With the preceding sketch of the burner processes in mind, it may be seen that the following criteria must be satisfied for satisfactory operation:

(1) The fuel spray must be fine enough to supply fuel vapour at a rate greater than that at which it is being consumed by burning. Furthermore, it must be distributed so as not to crack on the walls and so as to result in a uniform fuel/air distribution throughout a region of reaction comprising only a small amount of excess air. No fuel should find its way around this region of reaction.

(2) Sufficient feedback of heat should be provided to ignite the fresh fuel as early as possible, without vitiating the reaction region too much.

(3) The secondary air should be injected so as to result in a rapid decay to minimum size eddies and a uniform fuel/air distribution in the reaction region in conjunction with the fuel and primary air patterns. This mixing process requires mechanical work which is supplied by the kinetic energy of the jets.

(4) The dilution air should make the best possible use of the available pressure drop to redistribute the combustion gases, as it constitutes the major portion of the flow. This involves a neat balance between length of primary zone, length of dilution zone and size of dilution ports.

(5) The burner liner must be kept cool by means of convective transfer to the air entering it, but this air must not tax the ability of the dilution jets to properly redistribute the temperature profile. Furthermore, this cooling air should remain as distinct from the reaction region as possible.

#### Assumptions about the mode of operation

For the present analysis it will be assumed initially that:

(a) The fuel spray is sufficiently good to satisfy requirement (1), above. A deterioration of this assumption will occur at very low fuel flows.

(b) Condition (2) is non-critical. This is a realistic assumption for normal engine operation.

(c) Condition (3) implies that laminar diffusion is faster than macroscopic mixing, and therefore not critical. This assumption deteriorates as $Re_j$ becomes less than a certain constant for a given chamber.

(d) The quenching of the reaction by the liner can be kept negligible by keeping the reaction region sufficiently removed from the walls. This assumption deteriorates above some altitude condition.

(e) An application of results obtained with single jets injected at an angle to an air stream is adequate to describe the mixing processes assumed to govern the primary zone, and known to govern the dilution zone.

## DEVELOPMENT OF FORMULAE FOR THE MIXING PROCESSES IN A BURNER LINER

#### Description

Referring to Figure 1, the jet will have diffused at a distance $L$ from the hole to an unmixedness $\theta_c$ and to a penetration $h$, measured from the plane of the orifice to the centroid of the jet flow at $L$. If the characteristic property is temperature, the unmixedness is defined as:

$$\theta_c = \frac{T_m - T_{min}}{T_m - T_j}.$$

Similarly, $\theta_c$ can be defined in terms of, say, the fuel/air ratio of the two streams:

$$= \frac{f/A_m - f/A_{min}}{f/A_m - f/A_j}.$$

#### Assumptions for a real liner

In a flame tube, the jet flow will not be negligible compared with the main stream; there will be more than

one jet interacting; and normally the quantity of interest is $\theta_d$ defined as:

$$\theta_d = \frac{T_{max} - T_m}{T_m - T_j}$$

or

$$\theta_d = \frac{f/A_{max} - f/A_m}{f/A_m - f/A_j}$$

Therefore some further assumptions must be added to (a) to (e) already made:

(f) Jet interaction and non-negligible jet flow will result in $\theta_d \sim \theta_c$.

(g) $f/A_{max}$ in the second expression for $\theta_d$ is the effective $f/A_{max}$, insofar as combustion is concerned. This assumption is not exact because of turbulent fluctuations, but is no worse than other assumptions in the analysis.

**Experimental data on $h$ and $\theta_c$**

*Basic experimental correlation.* Lacking any thorough data on inclined jets of various velocities, an attempt will be made at using data for cases of $V_A = 0$ (Figure 1). The following formulae are from Reference 2 for $V_A = 0$, $T_j > T_L$ and round jets issuing from a pipe. The formulae are

$$\frac{h'}{D_j} = .945 \left(\frac{V_j}{V_L}\right)^{.612} \left(\frac{T_L}{T_j}\right)^{.478} \left(\frac{L}{D_j}\right)^{.265}$$

$$\theta_c = 1.01 \left(\frac{V_L}{V_j}\right)^{.383} \left(\frac{T_L}{T_j}\right)^{.114} \left(\frac{D_j}{L}\right)^{.705} \qquad (1)$$

*Adjustment for conditions in a burner.* To plausibly convert this set of equations to represent the case where $V_A \neq 0$ as is the case in real burners, the coordinates are transformed to a set where $V_A' = 0$. $V_j$ becomes $V_y$, $V_L$ becomes $V_L - V_A$, and $L$ becomes $L - V_A t$ (where a good approximation for $t = L/V_L$). The only new features about this system are:

(a) The mixing hole is receding from its position at $t = 0$ with a velocity $-V_A$. This probably speeds up the mixing.

(b) The quantities $V_L - V_A$, $L - V_A t$ can become negative through zero, so the absolute value only is used. Also, in the neighbourhood of $V_L - V_A = 0$ the converted formulae result in infinite $h'/D_j$ and $\theta_c$, and therefore additional experimental data must be used in this neighbourhood.

(c) The orifice equivalent to one of diameter $D_o$ for $V_A = 0$, is an ellipse of width $D_o$ and length adjusted to produce the same effective flow area, $\pi/4D_j^2$.

Using this approach, the equations become

$$\frac{h'}{D_j} = .945 \left(\frac{V_y}{V_L}\right)^{.612} \left(1 - \frac{V_A}{V_L}\right)^{-.347} \left(\frac{T_L}{T_j}\right)^{.478} \left(\frac{L}{D_j}\right)^{.265}$$

$$\theta_c = 1.01 \left(\frac{V_L}{V_y}\right)^{.383} \left(1 - \frac{V_A}{V_L}\right)^{-.322} \left(\frac{T_L}{T_j}\right)^{.114} \left(\frac{D_j}{L}\right)^{.705} \qquad (2)$$

It is apparent that at $V_A \sim V_L$ these equations cannot hold, so the factors of form $(1 - V_A/V_L)^e$ are replaced by $F_h$ and $F_\theta$, where $F_h \sim F_\theta \sim (1 - V_A/V_L)^{-1/3}$ in first approximation and for $V_A \ll V_L$ (Figure 2).

Eq. (2) then becomes:

$$\frac{h'}{D_j} = .945\, F_h \left(\frac{V_y}{V_L}\right)^{.612} \left(\frac{T_L}{T_j}\right)^{.478} \left(\frac{L}{D_j}\right)^{.265}$$

$$\theta_c = 1.01\, F_\theta \left(\frac{V_L}{V_y}\right)^{.383} \left(\frac{T_L}{T_j}\right)^{.114} \left(\frac{D_j}{L}\right)^{.705} \qquad (3)$$

*Further experimental results.* For $V_A \gg V_L$, experimental data obtained in this range must be used, and these are available in Reference 3. They are obtained with round pipes discharging a jet at an angle to the stream, and thus directly correspond to the data of Reference 2, where $D_j$ is the diameter of a round jet. The results are shown in Table 1 and plotted on Figure 2.

TABLE 1

$F_h$ and $F_\theta$ for $V_A > V_L$

| $V_A/V_L$ | 4.95 | | 4.82 | | 2.48 | | 2.42 | |
|---|---|---|---|---|---|---|---|---|
| $L/D_j$ | 6 | 8 | 5.7 | 7.5 | 5.2 | 7.5 | 5.6 | 7.5 |
| $F_h$ | 0.967 | 1.069 | 0.921 | 1.076 | 1.021 | 1.169 | 1.095 | 1.290 |
| $F_\theta$ | 2.51 | 2.29 | 2.66 | 2.41 | 1.725 | 1.658 | 1.995 | 1.645 |

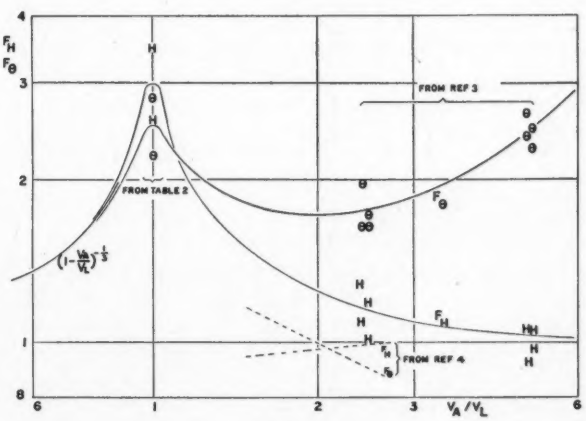


**Figure 2**
**Correction factors for $V_A \neq 0$**

Some further experimental results are available[4], and the 60° case in this reference supplies data closer to $V_A/V_L = 1$. Since the data points are not given, an analysis based on the correlation arrived at in this reference results in:

$$F_\theta \sim 1.4(V_A/V_L)^{-.50} \qquad 1.45 < V_A/V_L < 2.85$$

$$F_h \sim .9\,(V_A/V_L)^{.08} \qquad L/D_j \sim 20\; T_L/T_j \sim .67$$

It is considered, however, that these results are not too good on account of the narrow channel used (Figure 2).

*Data near $V_A/V_L = 1$.* Lacking any directly applicable results, it is assumed that the spreading of a round jet of initial velocity $V_y$ into a medium at rest represents the situation encountered here, where a jet is penetrating at initial velocity $V_y$, but at an angle to its own axis.

Furthermore, the turbulence of the medium being penetrated is being neglected by this assumption, which will result in high values for $F_h$ and $F_\theta$, although it should not affect the quotient too much. A fully developed turbulent jet of properties similar to those for the other data spreads according to the relationship:

$$\frac{V_y(y)_{max}}{V_y(O)} = 5\frac{D_j}{y} \qquad \text{(Reference 3)}$$

Integrating with time, and remembering that for $V_A = V_L$ $t = L/V_L$, arrive at:

$$\frac{h_{max}}{D_j} = 3.16\sqrt{\frac{L}{D_j}\frac{V_y}{V_L}}$$

Postulating a conical temperature distribution, analogous to the velocity distribution but 1.3 times as broad[2] it is found that the weighted average of the penetration $h_{ave} = 0.421\ h_{max}$. The choice of $h_{ave}$ implies the assumption that $h_{ave} = h'$. This is very nearly so, $\pm 10\%$, from data in Reference 5. Also, from Reference 3

$$\theta_c = 4.8\frac{D_j}{h_{max}} = 1.52\left(\frac{L}{D_j}\frac{V_y}{V_L}\right)^{-.5}$$

To be consistent with the rest of the data, and to bracket the range of $V_y/V_L$ and $L/D_j$ of immediate interest, $F_h$ and $F_\theta$ were calculated as shown in Table 2.

TABLE 2

$F_h$ and $F_\theta$ for $V_A = V_L$

| | | | |
|---|---|---|---|
| | $V_y/V_L = 1$ | $L/D_j = 5$ | $F_h = 2.58$<br>$F_\theta = 2.21$ |
| $T_L/T_j = .623$ | | | |
| | $V_y/V_L = 3$ | $L/D_j = 30$ | $F_h = 3.47$<br>$F_\theta = 2.80$ |

(The ratios are 1.166 and 1.240, $\sim$ 1.2)

Finally, by checking data gathered in Reference 5 against $F_h = F_\theta$ for $V_A = 0$, an approximate correction factor for the constants in Eq. (3) may be obtained, which will combine all the following corrections:

(a) ratio of $h_{ave}/h'$
(b) effect of $T_L/T_j \sim 1.4$
(c) effect of a sharp edged orifice of diameter $D_o$

The correlation is mediocre, but correction factors are estimated to be 0.70 for $F_h$, and 0.93 for $F_\theta$.

The formulae incorporating the corrected constant become:

$$\frac{h}{D_o} = .66F_h\left(\frac{V_y}{V_L}\right)^{.612}\left(\frac{T_L}{T_j}\right)^{.478}\left(\frac{L}{D_o}\right)^{.265}$$

$$\theta_d = .94F_\theta\left(\frac{V_L}{V_y}\right)^{.383}\left(\frac{T_L}{T_j}\right)^{.114}\left(\frac{D_o}{L}\right)^{.705} \qquad (4)$$

**Summary of assumptions about the mixing process**

(1) Assume that jet interaction and non-negligible jet flow will result in $\theta_d \sim \theta_c$.
(2) Assume that $f/A_{max}$ in the second expression for $\theta_d$ is the effective $f/A_{max}$, insofar as combustion is concerned. This assumption is not exact because of turbulent fluctuations, but is no worse than other assumptions in the analysis.
(3) Assume that a correlation for $V_A = 0$ and $T_L/T_j < 1$ is capable of extension to $V_A \neq 0$, $T_L/T_j > 1$.
(4) Assume that $h'$, the penetration to the peak of unmixedness, can be corrected to $h$, the penetration to the jet flow centroid, by the use of a constant factor.
(5) Assume that the effect of the velocity of the orifice in the moving set of co-ordinates is negligible.
(6) Assume that the theoretical form of $F_h$ and $F_\theta$ in Eq. (2) holds for $V_A \ll V_L$.
(7) Assume that the effect of turbulence in the liner flow is negligible.
(8) Orifices of equal width $D_o$ and equal effective flow area are equivalent.

**Effects of the different variables**

*Elimination of $D_o$ from Eq. (4).* In order to see how pressure drop, unmixedness, penetration, length and temperature are inter-related, $D_o$ is eliminated from Eq. (4) on the assumption that it can be sized to suit the other requirements. By obtaining $h/L$ rather than $h/D_o$, and dividing through by $\theta_d$, the following expression is obtained:

$$\frac{h}{L} \sim .66\frac{F_h}{F_\theta}\theta_d\frac{V_y}{V_L}\left(\frac{T_L}{T_j}\right)^{.364} \qquad (5)$$

The best guess about $F_h/F_\theta$ from data on Figure 2 is shown on Figure 3. It may be concluded that for given

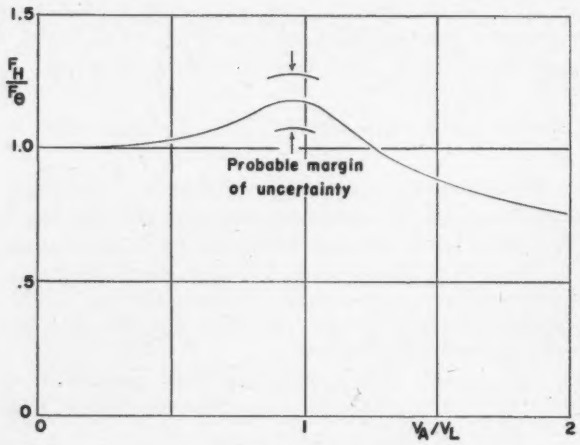


**Figure 3**
**Coefficient of Eq. (5), showing desirability of operating near $V_A/V_L = 1$**

$\theta_d$, $L$, $V_L$ and $T_L/T_j$, the maximum $h/V_y$ will be obtained near $V_A/V_L = 1$.

*Pressure Drop.* In order to relate Eq. (5) to the loss of total pressure through the burner proper, the equation $q = pV^2/2gRT$ is used, resulting in:

$$\frac{q_y}{q_L} = 2.3\left(\frac{h}{L\theta_d}\right)^2\left(\frac{T_L}{T_j}\right)^{.272}\left(\frac{F_\theta}{F_h}\right)^2 \qquad (6)$$

The normal dynamic head $q_y$ is related to the loss in total pressure in a manner depending on the exact configuration. In general, the wall friction inside the liner may be estimated on the basis of turbulent flow formulae. A momentum balance then results in a pressure drop estimate between the injection orifice and a region downstream, generally assumed to be fully mixed and uniform.

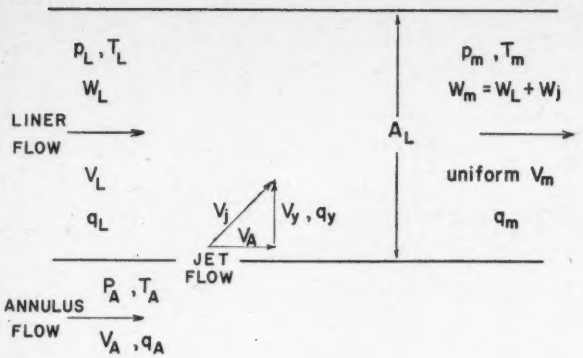


**Figure 4**
**Diagram for pressure drop calculation**

Considering the mixing process in a cylindrical, frictionless duct (Figure 4),

$$P_A - p_L = q_A + q_y$$

$$\frac{W_L}{g} V_L + p_L A_L + \frac{W_j}{g} V_A = \frac{W_L + W_j}{g} V_m + p_m A_L$$

Putting $V_A = V_m$ (which is near optimum from the mixing viewpoint for small $W_j$, and will not alter the qualitative picture while simplifying the relationships):

$$\frac{W_L}{g}(V_m - V_L) = A_L(p_L - p_m)$$

$$p_L - p_m = 2q_m\left[\frac{W_L}{W_m} - \left(\frac{W_L}{W_m}\right)^2 \frac{T_L}{T_m}\right]$$

Therefore

$$P_A - p_m = q_A + q_y + 2q_m\left[\frac{W_L}{W_m} - \left(\frac{W_L}{W_m}\right)^2 \frac{T_L}{T_m}\right]$$

but,

$$q_A/q_m = T_m/T_A \text{ and } P_m = p_m + q_m$$

and

$$\Delta P = q_y + q_m\left[\frac{T_m}{T_A} - 1 + 2\frac{W_L}{W_m}\left(1 - \frac{W_L}{W_m}\frac{T_L}{T_m}\right)\right] \qquad (7)$$

For a typical design, the term in $q_m$ is of the order of ¼ of $\Delta P_{tot}$, and wall friction is very small, about 5% of $\Delta P_{tot}$. A good rule-of-thumb is to take $\Delta P_{tot} \sim q_j$ as a first estimate.

*Further analysis of variables.* The effect of the cross sectional dimensions of the burner may be expressed as

$$q_L \sim W_L^2 R T_L / 2g P_L A_L^2$$

$W_L$, $P_L$, and $T_L$ are taken as constant, so that $q_L \propto 1/A_L^2$. For annular as well as cannular burners, $A_L = 2\pi r_L d_L$ where $d_L$ is the depth of an annular burner, or the "characteristic depth" of a cannular one; $r_L$ is the mean radius. This leads to

$$q_y \propto (h/L\theta_d\, r_L\, d_L)^2$$

by Eq. (6) and neglecting effects of $T$ and $F_h/F_\theta$. Now, $h$ is proportional to $d_L$, so that

$$(L\theta_d\, r_L)^2\, q_y = \text{constant} \qquad (8)$$

This shows that $d_L$ is relatively less important than the mean radius of the burner, insofar as it only affects the minor term $q_m$ in Eq. (7), where $r_L$ affects $q_y$ directly. However, $d_L$ cannot be decreased without affecting the conditions at which assumptions about laminar diffusion and quenching deteriorate.

All in all, it will generally be much more important to consider the outside casing of the burner than the inner one, as far as burner cross sectional area is concerned, and in many cases it may be desirable to use a larger inner casing diameter than is allowable from mechanical design considerations. The unmixedness $\theta_d$ is seen to have a similar effect to that of the other variables on the pressure drop. Its magnitude for the dilution zone is specified by the turbine inlet temperature distribution required; and for the primary zone, by the amount of excess air and the required combustion efficiency.

## CONCLUSIONS

(1) A series of relationships involving pressure drops, flows, temperatures and dimensions have been evolved on the basis of taking turbulent mixing[2, 5] as the controlling process in the primary and dilution zones of burners. These should be fairly useful in deciding questions, such as the burner envelope dimensions, can vs annular burners, hole size and distribution, pressure drop vs temperature profile etc.

(2) The pressure drop required for a given type of burner design varies about inversely with the square of the product of the length, the unmixedness and the mean liner radius (Eq. (8)).

(3) The velocity component of the jets parallel to the liner flow should be about equal to the velocity of the liner flow being penetrated, in order to obtain a given penetration and unmixedness from a minimal pressure drop.

(4) The lack of adequate experimental results is the major weakness of this presentation. The aspects in most urgent need of clarification are:

(a) The shape of the $F_h$ and $F_\theta$ vs $V_A/V_L$ curves, or families of curves.

(b) The effect on the correlations of injecting cold jets into a hot gas, instead of vice versa[2].

(c) The effect of injecting cold jets into a burning gas on the correlations.

(d) The effects of jet interaction and non-negligible flow, preferably under typical burner conditions.

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# SOME ASPECTS OF FUTURE AIR TRANSPORT POSSIBILITIES†

by Sir George Gardner*

*Royal Aircraft Establishment*

## INTRODUCTION

I AM greatly honoured to receive the invitation of the Canadian Aeronautical Institute to give this paper. The honour is in no way qualified by the fact that the Institute is a very recent foundation as compared with the Royal Aeronautical Society, to which I belong, which was founded in 1866 and of which many Canadians are distinguished members. It is indeed more important that powered flight was achieved in Canada 50 years ago than that there should have been a Canadian aeronautical professional institute at that time.

Long before man first flew some inspired pioneers were predicting widespread air transport, but even they could hardly have been expected to anticipate the glorious part played by aircraft and their pilots in the Battle of Britain, the overwhelming potential of the modern bomber armed with nuclear bombs, the efficiency of the modern unmanned flying machine, or the immense growth in civil air transport. In 1957 the world's commercial airlines carried $70.5 \times 10^6$ passengers and the freight traffic was $1.35 \times 10^9$ ton miles. The total distance flown was $1.6 \times 10^9$ miles. In addition, many thousands of aircraft are operated by private individuals and by commercial firms for many purposes. The wishes of the pioneers would be better met, however, if a higher proportion of airline tickets were purchased by the common man in order that he and his family might travel more freely by air for their own private purposes. The pioneers would be greatly surprised at the achieved speed of flight, and startled by the size and degree of consolidation of modern airfields. In this context, it is interesting to read the first specification (Appendix I) for an aeroplane, issued in 1908 by the Establishment with which I have the honour to be associated. The speed was to be not less than 25 mph and the airfield size was 10 acres (220 yards square). The area of London airport is 2,827 acres!

The pioneers would also be disturbed that, after more than 50 years of flight, the vagaries of weather still impose great penalties and they would be concerned whether the provisions to ensure safety were keeping in step with the progress in other directions.

Following this line of thought, I propose to examine in this paper some aspects of the growth in and future opportunities for the development of air transport. The pursuit of greater safety and regularity must play a large part in such development and I regret that it is not possible, owing to limitation of space and time, to survey in this paper progress and promise in these fields. However, one such subject, the problem of landing aircraft in zero visibility weather conditions, is examined in some detail because of its particularly close relation to the theme of the rest of the paper.

## VOLUME AND COST OF AIR TRAFFIC

### Air travel market

In speculating upon the future course of air transport, it is well to begin by glancing at its past and its present. The spectacular rise in aeronautics in this century has been stimulated largely by two wars, as the result of which air transport has grown in the wake of the rapid military developments. It seems likely, however, that civil transport will have to stand increasingly on its own feet in the future.

At present air transport is the only form of transport in which passenger traffic and passenger revenue predominate. The ratio of passengers to freight in ton-mile units is about 3/1. In order to win traffic the convenience and speed of air travel must outweigh the apparent extra cost compared with other forms of transport. In contrast to all other transport media, it has no speed ceiling if costs are disregarded. Thus it can offer a flexibility in operating speeds, which at present range from 150 to 600 mph, satisfying the needs of widely different sections of the travelling public.

It is very likely that the next decade will see a further increase in speed and the emergence of the supersonic airliner.

Although the air still remains a high cost means of transport the speed and convenience which it offers is fully marketable at the fares charged — witness the relatively high load factors of modern transport aircraft. As

†Paper read at the Special Anniversary Meeting of the C.A.I. in Montreal on the 23rd February, 1959.
*Director

a means of passenger and freight transport, especially over the longer distances, aviation is now an essential feature of the national economy of any of the more developed countries.

As yet, however, their traffic and earnings are small compared with those of ships, rail and roads.

BRITISH TRANSPORT STATISTICS 1954-5
FIGURES ARE RELATIVE TO "AIR"

| | Ton miles | Passenger miles | Total revenue | Revenue per tm |
|---|---|---|---|---|
| Air | 1 | 1 | 1 | 1 |
| Rail | 104 | 12 | 7.3 | 0.068 |
| Shipping | 2720 | 2.7 | 12.5 | 0.004 |
| Road | 58 | 26.5 | 7.8 | 0.131 |

However, air traffic is expanding faster than that of any other form of transport – at the rate of about 15% per annum for both passengers and freight (Figure 1). In spite of this large growth, however, air transport has as yet made only a slight impression on the mass of the people even in the areas of highest prosperity. About 25% of the USA population make one flight per year, and as those who travel by air usually do so frequently, the percentage of individuals is probably much less. This figure is much higher than anywhere else in the world except Australia; in Europe it does not much exceed 2%.

The picture at present is clear enough. Air transport in the main, after allowing for the introduction of the tourist ticket, is a service for an unduly limited number of people – the Government official, the business executive and those with higher incomes. In one respect only is air transport showing a popular impact and that is in a large extension to the holiday radius for the middle income group.

The growth of air transport at about 15% per annum is dependent on three factors:

(a) increase in world population and industrial production,
(b) a growing air-mindedness, and
(c) reduction in air transport costs relative to world prices.

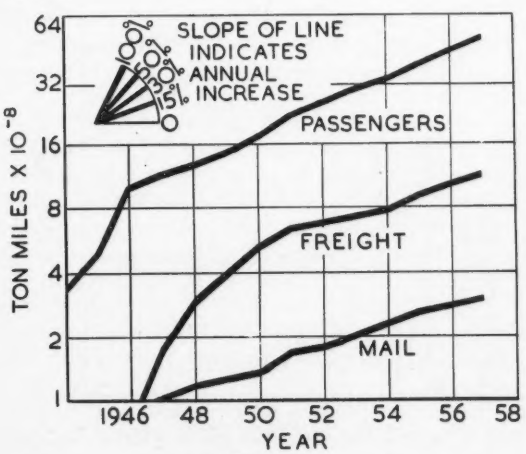



**Figure 1**
**Growth of world scheduled air transport (excluding China and USSR)**

How much of the traffic increase is due to each of the above factors is difficult to decide but it would be safe to assume that air traffic will continue to grow at the above rate provided that costs do not rise and that the existing general conditions are maintained. It must be the object of all operators so to reduce operating costs that the level of costs per ton-mile continues to fall, and thus make possible the continued reduction in the level of fares and rates on which the expansion of the air travel market must largely depend.

The rate of re-equipment of the larger airlines has increased markedly in recent years, mainly due to the jet aircraft orders. The charges associated with so large a

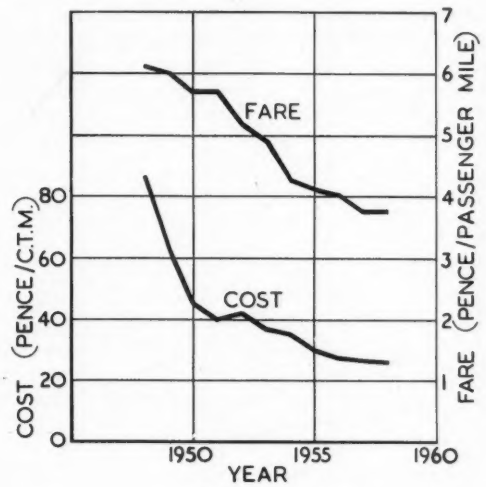



**Figure 2**
**Trend in fares and costs corrected to 1947-8 values**

commitment will represent an increasingly large proportion of operating costs over the next ten years; there will undoubtedly be pressure to slow down the rate of re-equipment and to extend commercial lives and thus depreciation periods substantially beyond the seven years or so which is now general practice.

Figure 2 shows how our fares have decreased relative to general prices over the last 10 years, for the typical case of one British operator. The slope of this curve must ultimately decrease as we run out of aircraft development ingenuity, but what we are really interested in is air fares relative to income levels; this is a steeper curve than that shown if we are in an era of increasing productivity which means greater incomes relative to prices. Thus any trend in the general world position, such as cheaper power by nuclear energy, leading to greater productivity will tend to increase air traffic quite apart from what the aircraft designer or operator can do in reducing air travel costs.

It is, of course, likely that more efficient aircraft will continue to emerge for many years to come. It was recently pointed out by N. E. Rowe that in efficiency there has been a tenfold advance over the past 40 years, as measured by the parameter *payload* × *speed*/*gross weight* and, in spite of the accompanying growth in complexity and basic cost, the operating costs, as reflected in Figure 2, have decreased spectacularly. Prediction of technical advances is always difficult. In fact,

long range accurate prediction is impossible because it is made in ignorance of the fruits of continuing research and experience; any attempt at prediction tends therefore to be conservative; this has nearly invariably been so in the past in the aircraft field. However, some factors and possibilities are examined in this paper in an attempt to see into the crystal ball – even if only in a very small way.

Air transport has already ensured its most obvious gains by establishing a very long range facility – stage lengths of 3,000 miles are now beginning to be commonplace – and given this pattern there may be profit in further reducing journey times by increased speed.

Mass travel, however, may very well grow over the smaller stage lengths and in this area the attraction of flying will depend very much on the cost of the ticket. I have, therefore, chosen to illustrate two aspects of the shorter range market – one in the passenger and the other in the freight type of slower speed aircraft.

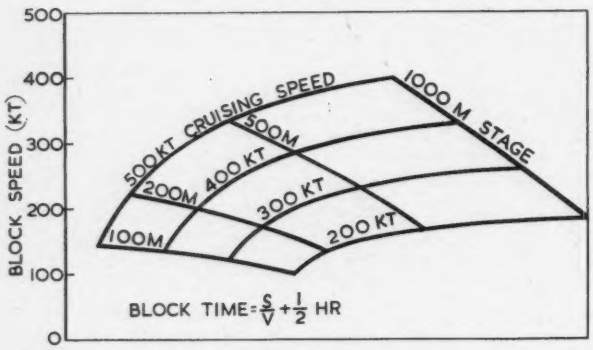



**Figure 3**

**Variation of block speed with stage length and cruising speed**

**Trends of costs**

*Passenger traffic*

I have suggested that there are cogent arguments for the steady growth of air passenger traffic as general standards of living rise, combined with a decrease in operating costs as we continue to progress in aeronautical developments. I believe it will grow particularly in those regions whose centres of population are sufficiently widely separated to make the attraction of extra speed worthwhile in competition with surface transport. Such a growth is, in fact, already taking place in the Australian outback, in Canada, and in other large territories with untapped production potential where centres are perhaps 300-500 miles apart, and is helped by some lack of good trunk roads and railways.

I have therefore chosen to illustrate some of the factors which influence the cost and convenience of air travel over stage lengths from 100-1,000 miles. The main factors are block speed, utilization and payload size. If we assume that block time can be sufficiently accurately expressed as

$$t = \frac{S}{V_c} + \tfrac{1}{2} \text{ hours}$$

where $S$ is stage length and $V_c$ is cruising speed, the ½ hour being the allowance for takeoff, climb, descent and landing, then Figure 3 shows block speeds for

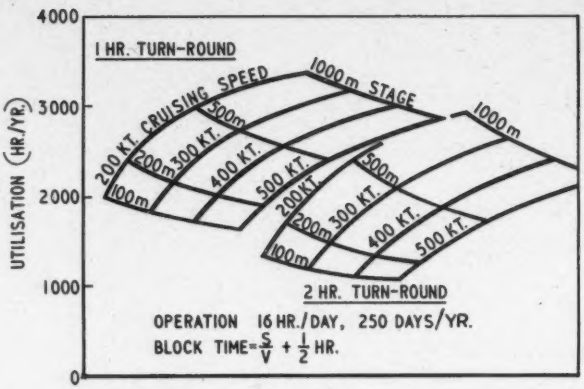



**Figure 4**

**Variation of utilisation with stage, speed and turn-round time**

various cruising speeds and stage lengths. It illustrates the rather obvious points that over the smaller stage lengths high cruising speeds offer little advantage in block speed, and that block speed is significantly less than the cruising speed.

Using the same expression for block time, and assuming a utilization based on 16 hours/day operation for 250 days/annum, Figure 4 shows the difficulty of getting a high utilization over the small stage lengths, the importance of a small turn-round time and the adverse effect of increasing speed on utilization. In actual practice a step function would be introduced at certain speeds and ranges where the number of trips per day changes. To illustrate the general effect of these parameters on cost, I have examined a family of turboprop aircraft flying at about 350 knots, each designed for a particular stage length and carrying a payload of 27,500 lb when operating from a 7,500 ft airfield. Engine characteristics are those corresponding to the Rolls-Royce Tyne. Figure 5 shows the progressive increase in percentage payload that can be carried as the stage length is reduced, i.e. the aircraft are getting smaller, accompanied by a small decrease in the optimum speed. The dotted curves on this figure show that not much is lost when an aircraft

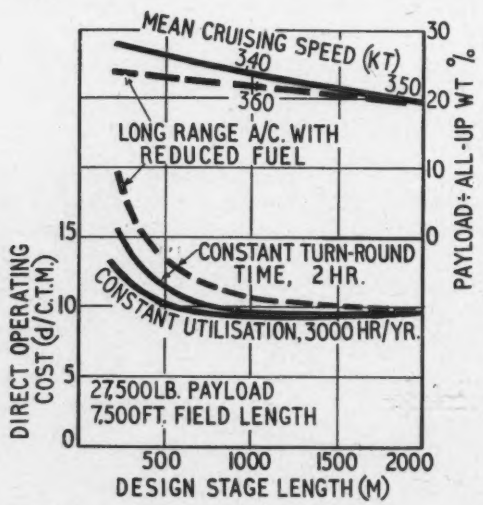



**Figure 5**

**Effects of design stage length on costs of a family of turboprop passenger aircraft**

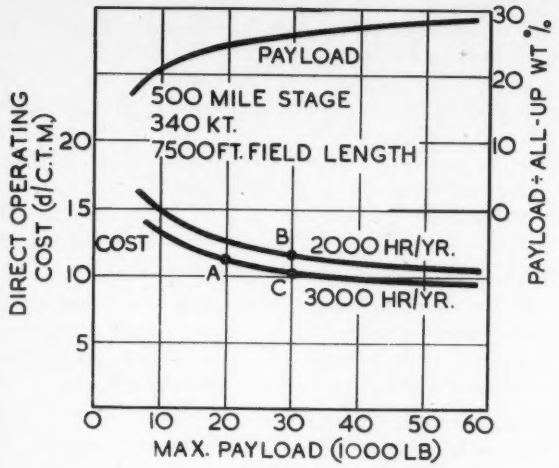



**Figure 6**
**Effect of payload on costs of a passenger aircraft**

designed for the longer stage is operated over the smaller stage lengths with reduced fuel load.

The direct operating costs per capacity ton-mile are given in Figure 6, both for a constant annual utilisation of 3,000 hours and the utilisation that would be derived from Figure 4 for a turn-round time of 2 hours. The cost increase at the smaller stage lengths due to the smaller block speeds and utilisation is clearly shown, together with the small difference between the optimum aircraft and an aircraft designed for a longer stage. When indirect costs of about 10d/ctm are added, one sees that a reduction in design range from 800 to 200 nautical miles might add 15% to the cost per passenger mile.

We also note from Figure 6 the effect that an increase in payload will have in reducing costs. In this graph the revenue payload increases to 60,000 lb, corresponding to about 250 passengers. For this type of short range aircraft (design stage length 500 nautical miles) the major part of the operating costs is dependent on first costs, so that the operating cost is more sensitive to utilisation than that of longer range aircraft.

To carry a fixed amount of traffic we have, for example, the choice between operating a small aircraft at a high utilisation (Point A, Figure 6) or a larger aircraft at a lower utilisation (Point B, Figure 6). The comparison shows little difference in cost. However, the larger aircraft can be justified if sufficient extra traffic is attracted by the lower cost (Point C, Figure 6).

We have seen that a reduction in stage length enables a larger percentage payload to be offered in spite of the increasing adverse effect of fuel reserves as stage length decreases. The decreased block speed over the smaller stage lengths together with the smaller utilisation that can be offered with a reasonable turn-round time are such that the effect of the increased payload is offset unfortunately, and costs per ton mile actually increase. So that unless short range flight can be made without the large fuel reserves, we do not obtain the hoped-for gain.

I have shown that a significant gain in costs could be achieved by increasing the size of aircraft at least up to 150 passengers (about 35,000 lb payload) if the aircraft can achieve a high load factor. The advantage to be taken of this will depend on how far the operator is able to resist the demand for a high frequency on the short range service, but I suspect the gains are not large.

I conclude that the most profitable way to reduce fares while offering a short range service is to concentrate on the engineering – to produce a simple aircraft with the aim of reducing first costs per pound weight, and of increasing overhaul life of the powerplant, which together influence half the direct operating cost in this type of aircraft.

*Freight*

It was mentioned earlier that at present air transport is the only form of transport in which passenger traffic and passenger revenue predominate.

Interest in recent years has concentrated on the exploitation of the passenger market for air travel – we have had the long range big jets followed by the incursion of jet aircraft into the medium range bracket. The growth of air freight traffic has largely followed that of passenger traffic in that most of the traffic was carried in passenger aircraft; I suspect that in both fields most of the growth has been due to the fall in rates relative to general world prices. Since there is considerably more potential freight traffic available in the world than passenger traffic, a substantial reduction in air transport costs would produce a disparity between total traffic in freight and passengers and introduce a need for specialized freight aircraft. I believe that freight traffic is almost entirely limited by cost and if this is accepted a relationship can be established between freight traffic and freight rates. An interesting exercise on these lines has been carried out by F. Robertson of Short Bros. and Harland, on the basis that 5% of the value of a commodity is the maximum which an importer or exporter will pay for air transport. By tabulating the mean value of each commodity in terms of weight in the UK in 1955, the total traffic in each commodity, its value, and by assuming that the mean stage length is the distance from London to each country's capital, one can identify those commodities which are suitable for air freight to each country at various values of pence per ton-mile, and thus show a predicted relationship between the value of airborne exports and air freight charges (Figure 7). At an

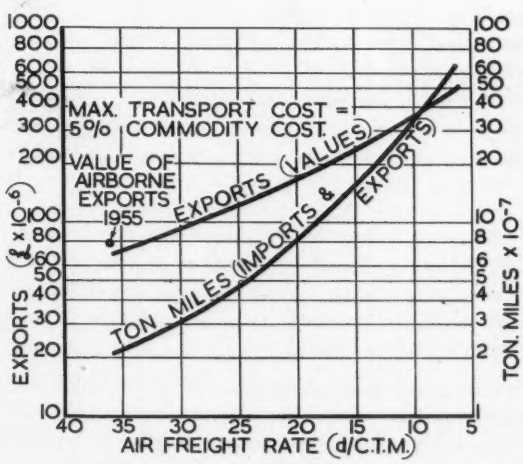



**Figure 7**
**Variation of freight traffic with cost**

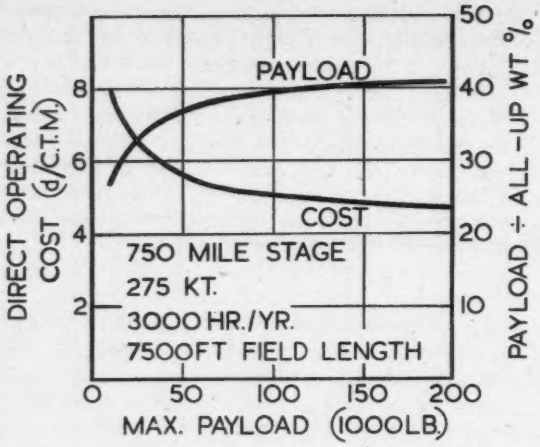



**Figure 8**
**Effect of payload on costs of a freighter**

air freight rate of 36d/ton-mile, which was about the average for 1955, UK airborne exports were about £78 million compared with £69 million predicted.

Taking the entire UK import and export potential, Figure 7 shows the predicted relationship between the volume of air freight in ton miles and air freight charges. If one could halve the rate from 36d to 18d/ton-mile the freight traffic could increase by 500%.

As shown in Figure 8, one fruitful way of contributing to reduction of costs is by increase of payload (and size of aircraft). Keeping airfield performance and cruising speed constant, an increase in payload from 10,000 lb to 100,000 lb reduces direct operating costs by 30% on a 275 knot turboprop aircraft. Similar trends would be expected in freighter aircraft of higher cruising speed. The figure illustrates the point that beyond a certain size it is not profitable to increase payload if a given standard of airfield performance is to be maintained.

The increase in percentage payload as the payload is increased is largely due (at the smaller payloads) to some parts of the equipment remaining fixed in weight plus increasing efficiency of fuselage weight per pound of payload. The decrease in slope at the higher payloads is largely due to the increase in wing weight with size of aircraft, the other two factors still operating in the favourable direction but having a smaller effect.

Side by side with any increase in freight traffic must come substantial development of the handling facilities at the terminal airports, or even the provision of special airports for freight, just as separate passenger and cargo docks are normally provided for shipping. The improvement in handling facilities can lead to a substantial reduction in indirect costs, help to achieve reduction in freight rates and lead to a greater demand for the larger specialized freight aircraft.

## SOME FUTURE POSSIBILITIES

### Effect of laminar flow

For many years aeronautical engineers have given serious consideration to the practical application in aircraft of reducing the skin friction forces arising from the viscosity of the air by maintaining the boundary layer flow in a laminar, or smooth, condition, rather than the more usual turbulent condition. In the earlier studies the application was thought to be restricted to unswept wings and, although significant economic gains could be predicted as the result of sucking the air continuously from the boundary layer through some kind of porous surface or closely spaced slits to maintain a laminar condition, the unswept laminar flow aircraft was not able to achieve the competitive and selling power of the higher speed given by swept wing jet aircraft.

Recent work has suggested that the maintenance of laminar flow on swept wings should be practicable, although with somewhat larger suction qualities, and has reawakened interest in the practical applications.

Laminarisation of the wings and tail unit of a conventional aircraft could increase $L/D$ to about 30, including the drag equivalent of the pump power, i.e. almost double that obtainable without suction. With laminarisation of the whole aircraft including the fuselage $L/D$ treble that of the conventional aircraft may well be feasible, but much research is needed in this case before full-scale application can be envisaged, especially if one includes provision for cut-outs such as windows and doors. The effect of the drag reduction is presented in a dramatic way by plotting it on the curve in Figure 9, due to N. E. Rowe. (Ratio of profile drag to turbulent skin-friction drag $\approx 0.55$.)

The reduction in drag achieved by maintaining laminar flow over the wing and tail unit is, of course, only obtained at the expense of some additional weight – the weight of the suction surfaces, of the suction pumps, drives and ducting, and of structure weight due to the different compromise on wing loading and aspect ratio. To offset part of this we may expect some reduction in powerplant weight.

The most obvious application for the laminar flow aircraft is at long ranges where the high cruising efficiency can reduce significantly the high fuel load carried

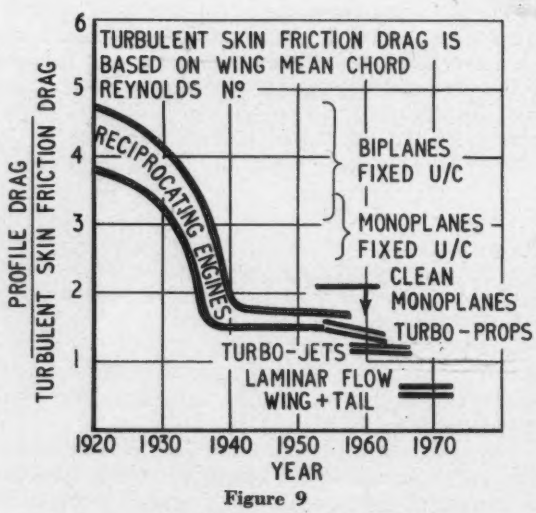



**Figure 9**
**Trend in profile drag**

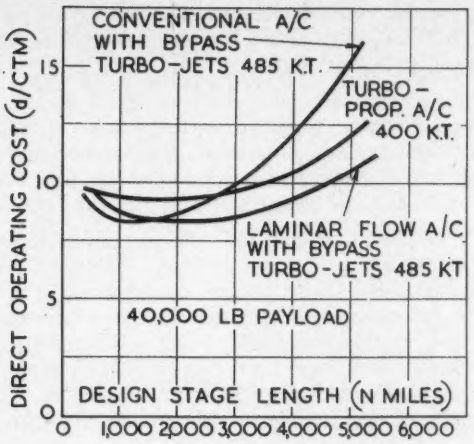



**Figure 10**
**Comparison of operating costs of laminar flow and conventional aircraft**

on the conventional aircraft. At small ranges the extra weight offsets the effect of the drag reduction since the fuel load is small, and the aircraft is then heavier than the conventional aircraft.

Typical variations of the operating cost of laminar flow turbojet aircraft and of conventional turbojet and turboprop aircraft, designed to operate from large airfields and to carry a payload of 40,000 lb over various ranges, are shown in Figure 10, where each point on the curve represents an aircraft designed for that stage length, and assuming that the particular size of engine required is available. In this figure the laminar flow aircraft is assumed to have the same first cost and same maintenance costs per pound of airframe weight as the conventional turbojet aircraft and fuel costs for all aircraft have been taken as 18d per gallon. At the trans-Atlantic stage length of 3,000 nautical miles, the direct operating costs are shown to be about 15% lower for a laminar flow aircraft than for a conventional turbojet design having the same powerplant characteristics and cruising speed. The gains come almost entirely from the smaller quantity of fuel required, the empty weights being approximately the same. The total operating costs including indirect costs would be about 7% lower. At the 5,000 mile stage length the reductions in direct operating costs and total operating costs are doubled at 28% and 15% respectively.

It seems that substantial savings in direct operating costs could be expected from a laminar flow transport, provided the following assumptions were justified:

(a) the first cost per pound is the same as for an orthodox aircraft,

(b) the maintenance cost per pound is the same,

(c) fuel costs are not significantly less than 18d per gallon,

(d) the problems of surface contamination could be overcome without undue complication, and

(e) the aerodynamic and structural design problems could be solved.

I feel reasonably optimistic about (e). I think we must expect some increase in first costs and maintenance costs, the magnitude of which cannot be adequately assessed without experience on some operational aircraft of reasonable size, while the fuel cost is obviously a dominating parameter in the comparison. I am left with the conclusion that though further research and operational problems remain to be solved before this promising idea could be applied to a large transport aircraft, there is at least a real incentive to try to solve them.

**VTOL and STOL**

It is felt that some consideration in this paper to the place of VTOL and STOL schemes is appropriate. The helicopter exists as a successful VTOL type but the upsurge of interest throughout the world in other types is evidence enough of its limitations. The configuration which confers the VTOL capability is very inefficient in normal forward flight and whilst improved helicopters will emerge for their special uses, these are unlikely to meet many of the needs which may be satisfied by other VTOL types.

When considering the application of VTOL to aircraft operation, two main questions have to be answered. Is it feasible and is it worth doing? Generally the answer to the first is "yes", provided one is prepared to pay for it. As regards the second, some of the military needs are obvious, such as freedom from dependence on runways of all military types and the application to operation from naval carriers. There is also great interest in the civil applications, such as the need to transport passengers to and from points closer to centres of population than existing airports, the urge to reduce landing speeds and the possibility of operation in areas as yet unserved by air transport. Another possibility, applicable more specifically to supersonic aircraft, is the freedom to design the aerodynamic shape exclusively for efficiency at high speed.

We are certainly not devoid of ideas for exploring VTOL – rather are we embarrassed by the need to make a choice between the many schemes which have been suggested, ranging from the provision of vertical thrust by the familiar helicopter rotor to propellers, fans and jet engines in increasing order of jet velocity and decreasing duration of hovering. We can use the same powerplant for both horizontal and vertical flight, separate powerplants for each phase, or use the same powerplant but with augmentation when in vertical flight. A large number of these methods are being extensively investigated throughout the world by research aircraft, many of them with airworthiness standards that do not give complete safety in all phases of the flight plan should a single powerplant fail.

Flight experience in the UK to date has been mainly on VTOL and I shall concentrate on this aspect in this brief review. I can best illustrate the problems and achievements of some of the VTOL schemes by a brief description of some of our own work. We started with

**Figure 11**

the Flying Bedstead (Figure 11), a concept which is now familiar and used in a number of other countries including the USSR. Its purpose was to make experiments on the control of a machine mainly in the hovering phase by small jets of air which are fed from the main engines through a suitable automatic control system operated by the pilot. It was demonstrated that such a control system was entirely practicable and it has led to the development of the S.C.1 (Figure 12) – a research aircraft – to investigate the problems of stability and control in the transition phase from vertical to horizontal flight and return.

*Short S.C.1–VTOL research aircraft*

Two aircraft have been built. The first has been flying since April, 1957, as a conventional aircraft, without either its lifting engines or the autostabiliser, and has demonstrated satisfactory behaviour within the normal flight envelope.

The second aircraft is fully equipped with four lifting engines plus one for propulsion and, since May, 1958, has been engaged in hovering tests, both in the "gantry" and in free flight though it has not yet flown as a conventional aircraft. The excellent response characteristics of the R.B.108 engines have given perfectly satisfactory height control without having to resort to artificial damping. Probably equally important, a background of control engineering experience is being built up in a field in which automatic equipment using electrical signalling is not simply an aid to the pilot but a vital part of the control system. "Reversion to manual" is no safeguard and reliability of a very high order is demanded.

**Figure 12**

Following the demonstration of a transition from hovering to normal flight and back again to a vertical landing we aim to work up, in time, to something like an automatic landing using those landing approach paths that are most practical and economical in fuel and the radio aids likely to be applicable in this problem.

We believe that the S.C.1 will give valuable experience of all the major stability and control problems which are likely to be present on any jet lift VTOL aircraft, irrespective of whether the lift is provided by direct jets, high bypass ratio engines or ducted fans. We also consider such an aircraft can be used to explore the problems associated with STOL as opposed to VTOL, using part of the lift engine thrust to provide lift.

As a result of the work done to date we feel that autostabilisation will generally be required. Automatic means of takeoff and landing may well be desirable to reduce the amount of fuel expended in these phases of flight, particularly for those schemes with a high consumption in hovering, but under reasonable weather conditions we consider the pilot could land accurately on a small area without the aid of a programmed manoeuvre. In order to exploit adequately the potentialities of VTOL in various specialised roles, particular attention will have to be paid to airworthiness safety standards in the event of partial powerplant failure, and to the noise problem in both its nuisance and structural fatigue aspects. We shall also need experience of the behaviour in gusts, though we do not believe the problem here is so serious as for the STOL aircraft which relies on a very high lift coefficient.

The S.C.1 is lifted by the thrust from high velocity simple jet engines and earlier studies, in particular the ideas of A. A. Griffith, related to aircraft with this type of powerplant, installed as separate engines for the lifting phase only. For a number of VTOL applications, a lower fuel consumption in hovering and a low noise level would be essential and the addition of fans in one form or another to simple jet engines has been suggested. One suggestion is to use integral ducted fan engines, and another to use wing or fuselage immersed fans mounted away from the gas generator and driven by shaft or pneumatic drive.

In the operational evaluation all schemes at present proposed for STOL and VTOL involve some appreciable performance penalty. In this respect the runway remains the most efficient and simple means of getting aircraft into the air with the aid of an undercarriage, and I believe that every time a medium or long runway is available it will be used. The efficient use of STOL and VTOL devices demands an aircraft which has to be specially designed from the start. In fact, the major key to a successful aircraft of this type is the development of a lightweight efficient powerplant.

I do not intend to enter the lists with the advocates of various schemes to determine their best regimes of operation. The small difference in total engine plus lifting fuel weight between the extremes of schemes advocated for VTOL suggests that the choice will depend more on factors of airworthiness and engineering complexity than on pure performance grounds.

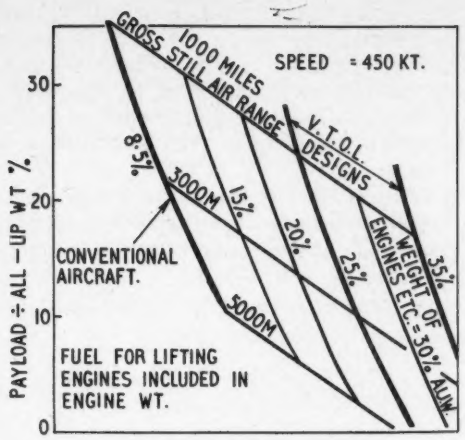



**Figure 13**
**Percentage payload for conventional and VTOL aircraft**

To give some idea of the importance of engine weight for the VTOL aircraft, Figure 13 has been prepared to show a carpet of percentage payload which can be offered for a series of aircraft of 450 knots speed for various still air ranges and powerplant weights. The powerplant weight includes both propulsive and lifting engines in the installed condition plus fuel in the VTOL case, and the structure weight is 25% all-up weight throughout. For the conventional aircraft a total powerplant installed weight of about 8-9% all-up weight is typical and we get the heavily lined curve on the left. In order to provide a thrust/weight ratio of about 1.2 for the VTOL aircraft (compared with 0.25 for the conventional aircraft) a total weight of engine installation of the order of 30% all-up weight is required.

The VTOL regime is therefore away on the right of the picture in the area indicated in which percentage payload is likely to be about half that of the conventional aircraft. To translate these answers into costs is difficult, but direct operating costs would be expected to increase more rapidly than the decrease in percentage payload, owing to the greater proportion of engine costs in the VTOL aircraft.

The economic account of VTOL therefore seems at present to be rather heavily against an easy passage to acceptance, except in some special applications. In general, VTOL configurations can become STOL merely by overloading, and I am sure that there will be pressure to reduce costs by using them as often as possible in this manner.

**Possibilities of high speed flight**

*General*

The rapid development of jet and rocket engines in recent years has made possible vastly increased speeds in flying machines, manned and unmanned. Supersonic flight is now a commonplace with fighter and research aircraft, while the instrumented satellites circling the Earth are visible proof of the progress made into the region of hypersonic velocities. It is, of course, only natural to wish to take advantage of these increased speeds not only for research and military purposes but also for transport purposes; speed in the air has always been an important selling factor and will continue to be so providing intolerable economic penalties are not involved.

The aim to exploit high speeds is encouraged by the characteristic of jet engines that their efficiency increases with speed. This quest for higher speeds, however, makes it increasingly difficult to maintain a high aerodynamic efficiency; once the speed of sound is exceeded the energy lost in the shock waves formed as an inevitable consequence can never be regained – the most that can be done is to minimise these losses. Great progress has already been made along these lines in the study of the aerodynamics of slender shapes. A figure of merit for aerodynamic efficiency is the lift/drag ratio ($L/D$) which for subsonic aircraft may be as high as 20, but even with the most careful design this will fall at the highest speeds where figures above 5 or 6 may be difficult to achieve.

Another phenomenon, which is likely to prove the biggest obstacle to sustained atmospheric flight at high speeds, is that of kinetic heating – that is the heat generated by the friction of the vehicle as it moves through the air. However, the rate of heat generation is a function of the density of the air through which the vehicle is passing – thus if the altitude is increased as speed rises, the surface temperature of the vehicle can probably be kept within manageable limits; say less than 700°C even at the highest speed envisaged.

Other phenomena also arise; for example, at speeds approaching satellite velocities the temperature of the air in the vicinity of the vehicle becomes so high that the fluid becomes dissociated or even ionised. Further, in order to reduce the kinetic heating effects we are forced to fly at such great altitudes that the air becomes so tenuous that we can no longer consider it as a continuous medium but rather as a stream of particles which may or may not carry electrical charges (this regime in which the mean molecular path is large compared with some characteristic dimension of the vehicle is generally termed "free-molecule flow"). Intermediate between this regime and that of the continuum, which has been the basis of our aerodynamics in the past, is another region in which the fluid cannot be considered as either continuous or a stream or particle (the "slip-flow" regime). Our knowledge of the characteristics of these types of flow is at present very poor and the effects on the aerodynamics of flying machines are already occupying a great deal of our attention.

*Hypersonic glider*

From the present transport viewpoint it is seldom that stage lengths of more than 3,000 nautical miles are required; it is therefore found that as cruising speed rises, the accelerations and decelerations occupy more and more of the total flight time. We should therefore tend to use the large amount of kinetic energy built up in the acceleration phase as efficiently as possible so that the journey is mainly accomplished during deceleration – thus result either the hypersonic glider concept, a vehicle skimming through the edges of our atmosphere at speeds approaching that of satellites, or ballistic flight where the journey is accomplished mainly outside the atmosphere and therefore without aerodynamic forces.

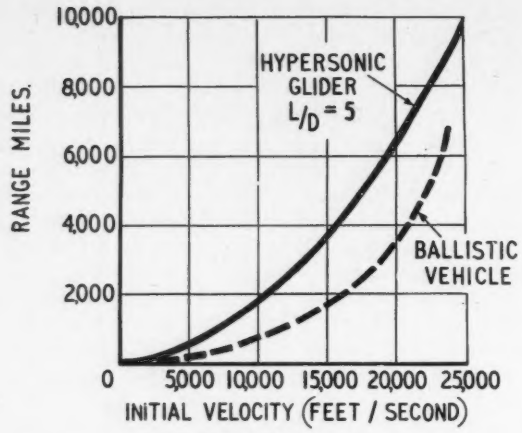



**Figure 14**
**Range of hypersonic and ballistic vehicles**

Some typical values of the ranges achievable with hypersonic gliders are illustrated in Figure 14 which relates to vehicles capable of producing a lift/drag ratio of 5 and starting at altitudes of around 40 miles (200,000 ft). It is seen that ranges of 2,000 and 10,000 miles, for example, can be achieved at velocities of 10,000 and 25,000 ft/sec respectively.

The range at a given starting velocity is virtually independent of wing loading but varies almost proportionally with $L/D$ ratio. The maximum deceleration experienced by the vehicle is also independent of wing loading but is approximately inversely proportional to $L/D$, e.g. for the curve given the maximum deceleration is about the same for all ranges at 0.2g.

For comparison, the range achievable with a ballistic vehicle is also shown; this travels clear of the atmosphere and hence encounters the heating problem most severely on re-entry — but although the descent from the edge of the atmosphere to ground level may only take 10 minutes, the heating rates and decelerations are very much higher than for the glider. It appears from the range aspect that a hypersonic glider having an $L/D$ ratio of 2-2½ is roughly equivalent to a ballistic vehicle; the maximum deceleration would be only ½g compared with around 2g-10g for the ballistic vehicle depending on whether lift is applied on re-entry or not.

The problems thrown up by such flight techniques will be formidable, in particular the heating and decelerations involved on reaching the denser regions of the atmosphere and control of the flight path, but there seems no reason to doubt our ability to surmount them.

*Supersonic transport*

Looking into the nearer future the rapid advances made in recent years in aerodynamic, engine and intake efficiency will permit reasonably economic supersonic flight. So far as can be foreseen now the direct operating costs are unlikely to be less than existing subsonic jets. Whether the increased speed will attract greater load factors as will be demanded by the need to keep in a strongly competitive market is more a matter for speculation and not for technical judgement. It can however be safely assumed that once a manufacturer produces a design for a supersonic aircraft whose estimated costs approach existing levels and once he can persuade a major airline to order a reasonable number of them, other operators will be subjected to intense pressures to follow suit.

I would therefore first like to make some crude predictions on the influence of speed on the direct operating costs and to follow with some observations on the influence of speed on other factors.

A rough approximation to the direct operating costs of a long range civil aircraft is given by

$$C = \frac{a}{S}\frac{W_F}{W_P} + \frac{b}{V_B}\frac{W_B}{W_P}$$

where $C$ is the direct operating cost per ton-mile, $a$ and $b$ are constants, $S$ is the stage length, $V_B$ block speed, $W_F$ fuel load, $W_B$ equipped airframe weight, and $W_P$ payload.

The first term in the above equation covers fuel costs and the constant $a$ depends on the price of fuel per gallon and the properties of the fuel load used on the average journey.

The second term covers such items as depreciation, amortisation, maintenance and crew costs.

In general fuel costs will increase with speed mainly because of the large reduction in $L/D$ which will increase the fuel load required for a given range and/or reduce the payload available.

The other than fuel costs in the second term above will be reduced by the direct effect of speed which, in effect, enables more work to be done with a higher earning capacity for the same maintenance, depreciation costs etc, but will also be increased due to the reduced payload available in a given airframe as a result of the increased fuel load. Both these effects roughly tend to cancel out so that the variation in other than fuel costs with speed tends to be less than the variation in fuel cost.

Typical values for trans-Atlantic operators using current values for lift/drag ratio etc for fuel and other than fuel costs (in pence/short ton-statute mile) are given below.

| Cruising Mach No. | 0.8 | 1.2 | 1.8 | 2.6 |
|---|---|---|---|---|
| Fuel costs | 3 | 5 | 10 | 12 |
| Other than fuel costs | 9 | 9 | 9 | 10 |
| Direct costs | 12 | 14 | 19 | 22 |
| Indirect costs | 12 | 12 | 12 | 12 |
| Total of operating costs | 24 | 26 | 31 | 34 |
| Ratio to present day subsonic jets | 1.0 | 1.08 | 1.3 | 1.4 |

You will note that in the table I have assumed that the indirect costs, such as publicity, sales services and overheads, are constant at 12d per short ton-statute mile. At present it would appear that estimates of such costs depend critically on the bookkeeping systems used by particular airlines. In practice one might assume that the increased traffic that can be handled with the higher speeds should lead to some reduction in such costs and so

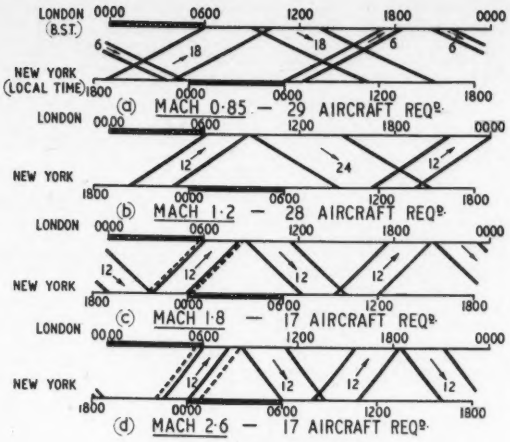



**Figure 15**
**Visualisation of time-tables for London-New York route (¼ hr frequency)**

the cost penalties of the higher speeds should be lower than those given in the table.

Four years ago, my predecessor at RAE, Sir Arnold Hall, in a lecture to the Institute of Transport predicted a future for the supersonic transport but at that time costs seemed to be some 2-3 times that of the subsonic long-range jet. It is a revealing consequence of the pace of aeronautical progress that today we can estimate costs which are half the previous values.

The most significant effect of speed is, of course, the increased traffic that can be handled with a given size of fleet. As discussed above, this reduces maintenance and depreciation costs as well as indirect costs or overhead costs. How important, economically, speed will be in practice is difficult to assess at this stage and I will present only the following illustration relating to time-tables over a given route (London-New York) at various speeds (Figure 15).

In this picture are illustrated typical timetables for four types of aircraft, of cruising speeds $M = 0.85$, 1.2, 1.8 and 2.6, each speed being approximately 50% higher than the last and each carrying the same number of passengers. The traffic is assumed to require 24 trips per day in each direction and the operational limitations are a 3 hour turn-round time at London and 2 hours at New York. The upper line represents a 24 hour period at London, the lower that at New York, while the batch of diagonal lines represent trans-Atlantic crossings with a 15 minute frequency. The number of crossings in each batch is marked on the figure. The periods from mid-night to 6 am are undesirable arrival or departure times. At the subsonic speed (journey time approximately 7 hours) 24 aircraft can each manage one return trip per day, all with desirable arrival and departure times. In addition, 3 aircraft grounded for routine checks and one spare aircraft at each end of the route make up a fleet of 29. This gives a peak utilisation annually of 4,000 hours per aircraft.

At $M = 1.2$ (journey time approximately 5 hours) 24 aircraft can still only manage one return trip per day, but with more spare time. Thus one spare aircraft is sufficient and a fleet of 28 is required, with peak utilisation 3,200 hours.

At $M = 1.8$ (journey time approximately 3½ hours) 12 aircraft can manage two return trips per day each, though if a 15 minute service is used, two trips either arrive or depart during the night, denoted by the dotted lines. As these aircraft have little spare time during the day, two spare aircraft are required and a fleet of 17 with 3,500 hours utilisation is required.

At $M = 2.6$ (journey time approximately 2½ hours) two return trips per day are still all that can be arranged and more night trips are necessary. Thus 17 aircraft with utilisation down to 2,600 hours and a less attractive time-table results.

We can thus see that the value of speed is a step function – going to $M = 1.2$ does not, in this particular case and with the assumptions outlined above, confer any reduction in the size of fleet, but $M = 1.8$ offers a significant reduction.

Such answers depend critically on the turn-round times assumed. If these could be reduced to say 1 hour at New York and 2 hours at London, it would be possible to operate 3 crossings per day with the $M = 1.2$ aircraft and 5 crossings per day with the $M = 2.6$ aircraft, and the fleet sizes would be correspondingly reduced. Nevertheless, it is probably true that for any particular route there is a particular speed above which significant reductions can be made in the size of fleet to cope with a given load. Such questions may be of dominating importance in choosing the next generation of civil transport aircraft.

One other problem induced by increased cruising speed is the higher takeoff noise associated with the high jet velocities of engines designed to give good cruise performance. This is off-set to a certain extent by the better climb performance due to the high thrust/weight ratios that would be required but much improvement will be required in this field before satisfactory civil operation can begin.

A final point is the much discussed possibility of VTOL for supersonic transports which, it has been suggested, will permit the design of an aircraft to be uncompromised by the takeoff and landing restrictions that normally apply. I believe that not only will the stowage of vertical lift engines and their satisfactory control create equivalent problems but that the weight penalties and maintenance costs will make an economic civil transport aircraft using such devices difficult to achieve in the near future. I do not want to deny the great probabilities of VTOL schemes; I believe that they have a promising future but that they must expect to earn their place by performing tasks entirely different from those at present undertaken by conventional civil transports. I believe that the first generation of supersonic civil aircraft will use conventional aerodromes and that concrete will continue to play an important part in civil aviation.

## THE WEATHER PROBLEM

### All-weather approach and landing

Although the problems of operating aircraft in all weathers have occupied the attention of engineers for about thirty years, bad weather, and in particular low

visibility, still remains the biggest single obstacle to be overcome in the achievement of regularity in air transport compatible with safety. When fog, low cloud, heavy rain or snow prevail and the weather deteriorates beneath permitted limits, the present high level of safety of civil transport operation is maintained only by a diversion of the aircraft to an alternative airport with the consequent reduction in operating regularity. It is estimated that about 90% of all diversions from an intended destination are due to bad weather in the region of the terminal airport.

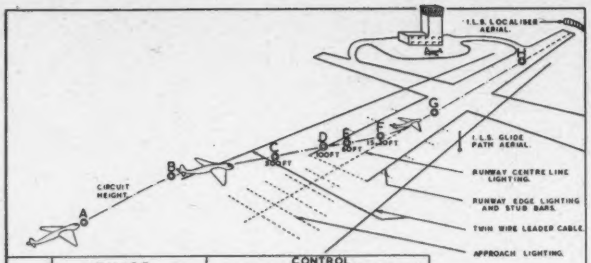
As the approach speed of the aircraft increases, and unfortunately this is the tendency with modern aircraft, the existing standards of safety can be maintained only by raising the operating limits and hence reducing regularity still further. More precise time-keeping in the terminal area will influence greatly the growth of passenger traffic particularly on the short stages where other forms of transport are competitive. It follows that the case for being able to land at an intended destination, irrespective of weather conditions, is overwhelming and, looking even further ahead, the economic operation of a supersonic aircraft may well depend upon its ability to land safely at first attempt.

Various radio and electronic aids are currently in use which permit safe approaches to be made in bad weather to a height of 150 to 200 ft in visibilities as low as 500 yards but the final landing has still to be completed manually by the pilot after visual contact with the ground. The problems facing the pilot in transferring from instrument information to visual information at a low height, and with only a few seconds left before landing, are still serious and are not likely to be eased by the introduction of the more modern aircraft. It can be shown that the minimum height to which a blind approach can be made is now limited, not so much by the instrument approach aid as by the time needed by the pilot to complete the manual landing following visual contact with the ground. To permit routine operation in conditions of zero or near zero visibility, it is necessary to eliminate the final visual phase completely.

For some time now the Blind Landing Experimental Unit of the RAE has been investigating various methods of achieving completely blind landings. Three examples of the work of this Unit will be described.

(a) The first method is in an advanced stage of development and consists of landing the aircraft automatically by coupling it through an automatic pilot in the aircraft to a radio guidance system, the pilot performing the task of monitoring the behaviour of the automatic equipment. It is clear from the success achieved that it is now time for civil aviation to consider in detail the implications of, and the requirements for, automatic blind landing in future aircraft.

(b) It may prove necessary to provide a second system completely independent of the automatic system which in an emergency will permit the pilot to land the aircraft manually. One such system, still in the early research stage, aims at presenting to the pilot in bad visibility a picture similar to the airfield lighting pattern seen at night in good visibility. This concept is called "Televiewer".




| | PHASE | CONTROL | |
|---|---|---|---|
| | | AZIMUTH | ELEVATION |
| A-B | AUTOMATIC APPROACH (TRACK). | I.L.S. LOCALISER, COMPASS. | BAROMETRIC HEIGHT. |
| B-C | AUTOMATIC APPROACH (GLIDE). | I.L.S. LOCALISER. | I.L.S. GLIDE PATH. |
| C-D | AUTOMATIC LAND (LEADER CABLE). | LEADER CABLE. | I.L.S. GLIDE PATH. |
| D-E | AUTOMATIC LAND (ATTITUDE). | LEADER CABLE. | FIXED ATTITUDE. |
| E-F | AUTOMATIC LAND (FLARE). | LEADER CABLE. | RADIO ALTIMETER. |
| F-G | AUTOMATIC LAND (KICKING OFF DRIFT). | COMPASS. | RADIO ALTIMETER. |
| G-H | MANUAL GROUND RUN. | LEADER CABLE, COMPASS. | |

**Figure 16**
**Automatic landing system**

(c) Finally a brief description is given of one of the important developments in hand to improve the more immediate problems of visual guidance for manual landing following an instrument approach.

**Automatic landing**

Figure 16 illustrates the various phases of the landing system. The landing starts with an "automatic approach" (A-B-C) which is already standard practice in many airlines. It is the most accurate of the several aids mentioned earlier which permit approaches to be made to heights of about 200 ft above the ground. Signals proportional to the vertical and horizontal displacement of the aircraft from the beam of the internationally accepted approach aid, called Instrument Landing System (ILS), are fed to the automatic pilot to lock the aircraft to the radio beam.

Despite its name, ILS is, in its present form, an approach aid only and in general cannot be used for guidance at heights below 100 ft and, hence, to permit the aircraft to complete the landing under automatic control, two new and more accurate guidance elements, magnetic leader cable in the horizontal plane (C-D-E-F) and radio altimeter in the vertical plane (E-F-G), are introduced during the last mile. Just before touch-down any drift due to crosswind is removed automatically (F-G) so that the aircraft lands aligned accurately with the runway. After touch-down the pilot disengages the automatic pilot and steers the aircraft to a stop using signals from the magnetic leader cable displayed on his flight instruments (G-H). A final feature is the inclusion of automatic speed control in which the engine throttles are moved automatically to maintain a constant speed during the approach (B-C-D-E) and then are throttled back to reduce the speed during the landing (E-F-G).

One of the great advantages of the system is its flexibility and in this respect it is superior to any other system under development. It uses the internationally accepted radio approach aid to the point where more accurate guidance is necessary and only at this stage introduces new elements into the system. Should future development improve the ILS approach guidance to such an extent that it can be used for landing guidance as well, the system will be easily adapted. This is a very promising line of development.

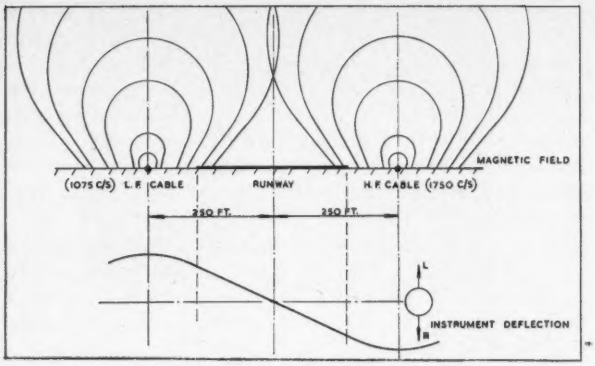



**Figure 17**
**Magnetic leader cable (schematic)**

It is impossible in a limited time to discuss the system in any detail but a few words on the more novel features may be of interest.

*Magnetic leader cable for azimuth guidance during landing*

The idea of leader cable is not new as it was first used in World War I to guide ships into harbour but it has since been developed to an accuracy of about 5 ft by BLEU for automatic landing. The ground equipment consists of two cables laid one on either side of the runway at a distance of 250 ft from the centre-line and extending for just under a mile into the undershoot area. The principle of operation is shown in Figure 17. Alternators feed each cable with a equal in amount current but of different frequency and at any point between the two cables the difference in the magnetic fields is a measure of the horizontal distance of the point from the runway centre-line. Hence an airborne receiver, discriminating in frequency between the two fields, can produce a signal proportional to the lateral distance of the receiving aerial from the runway centre-line. As is shown in the figure, the sensitivity is almost constant within the coverage of the cables.

The airborne equipment is shown in Figure 18. It consists of a rotating loop aerial and a simple three valve receiver whose output is low level dc current similar to that of the ILS receivers. Both ground and airborne equipment are extremely simple from the electronic point of view and this contributes greatly to their reliability, a feature of vital importance. The leader cable guidance signal is fed to the automatic pilot, which calculates and applies the amount of control required to land the aeroplane on the runway centre-line.

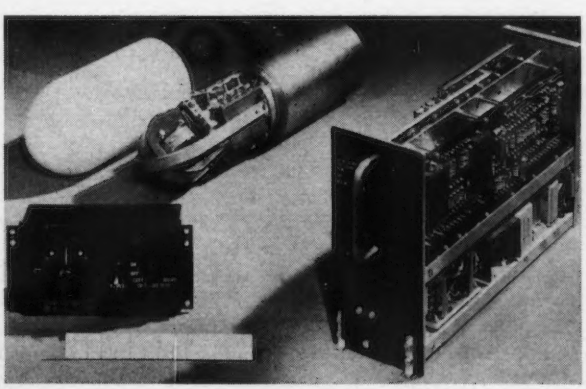


**Figure 18**
**Leader cable airborne equipment**

*Radio altimeter for vertical guidance during landing*

A very convenient and simple method of checking the glide path rate of descent and making a flare-out on to the runway is to make the flight path follow an exponential curve starting from the glide path. To do this, it is necessary to reduce the rate of descent in proportion to the height above the runway and this can be achieved by means of a control law of the form

$$\theta = h + k\frac{dh}{dt}$$

where $\theta$ is the pitch attitude demanded by the autopilot and $h$ is the height above the runway. With a time constant $k$ of 5 secs the flare-out starts at a height of about 60 ft and a very smooth flare-out under all weather conditions is experienced. A special radio altimeter has been developed to provide, with a very small time constant, an accurate and clean height signal suitable for differentiating, but clearly it can be used for accurate guidance only over even surfaces, such as the airfield and runway. It follows that with the present system there may be a gap in vertical guidance from about 100 ft, where the ILS glide path ceases to be useful, to about 60 ft, where the flare-out begins using the radio altimeter. During this phase (D-E of Figure 16), the aircraft is controlled on "open loop" by the autopilot to a mean pitch attitude datum automatically computed whilst the aircraft was flying down the glide path.

The radio altimeter has two height ranges 0-500 ft and 0-5,000 ft. On the low range a height accuracy of 3% of the measured height is provided with the ability to resolve height differences as small as 2 ft. Provision is made to permit an overall check of the equipment before flight.

*Automatic pilot*

Many hundreds of automatic landings have been made with a modified version of an autopilot currently used in British civil aircraft. The autopilot includes an "approach coupler unit" as a standard component for locking the aircraft to the ILS radio beam and, in principle, for automatic landing, the ILS signals to the coupler are replaced automatically by leader cable and radio altimeter. An additional control unit is necessary for the quick removal of drift prior to touch-down.

*Automatic speed control*

An automatic control is provided to maintain the airspeed constant during the approach phase (B-C of Figure 16) and, prior to touch-down, to close the throttles to the safe idling position in a prescribed manner.

It might be argued that automatic speed control is not essential to automatic landing. Whilst it is true that the throttle control could be left to the pilot, it is most important during the landing to have the control of the engine thrust related to other conditions in a known manner. This is more necessary with jet engines than with piston engines because of the different engine response

characteristic, and only with this control will it be possible to obtain the extra operational advantage of improved touch-down consistency from the automatic landing system.

*Instrument display*

Pilot monitoring of the satisfactory progress of the automatic landing is of great importance to the safety of the manoeuvre and to the peace of mind of the pilot. The extent of the monitoring required in a system fully acceptable to civil aviation with all the necessary safeguards is not yet resolved, but with minor modification the display used for monitoring automatic approach can be used for monitoring automatic landing so that at all stages of the approach and landing the pilot is presented with continuous information on the same instruments.

*Performance*

Over 2,000 safe and successful automatic landings have been made in all weathers, including fog, in both propeller and jet engined aircraft without any damage whatsoever to the aircraft. At times the landings have been made at the rate of more than 100 per month without adjustment or alteration to any of the instrumental controls. A wide range of wind conditions has been explored varying from 25 knots headwind to 10 knots tailwind and up to ± 15 knots crosswind component. Also rough air has been experienced on a large number of occasions.

| TOUCHDOWN PARAMETER | MEAN | R.M.S. |
|---|---|---|
| LATERAL DISPLACEMENT FROM RUNWAY CENTRELINE (FT) | 10 | 10 |
| LATERAL TRACKING VELOCITY (FT/SEC.) | 1·0 | 1·5 |
| RATE OF DESCENT (FT/SEC.) | 2·0 | 1·2 |
| LONGITUDINAL DISPLACEMENT ALONG RUNWAY FROM ORIGIN OF I.L.S. GLIDE PATH (YDS.) | 150 | 65 |

**Figure 19**
**Automatic landing performance in a medium sized jet aircraft**

Figure 19 shows the results of a statistical analysis of a representative sample of automatic landings.

It will be seen from the figures of lateral displacement and lateral tracking velocity that at touchdown the aircraft is very close indeed to the runway centre-line and is accurately aligned along the runway, due largely to the high accuracy of the leader cable guidance system. The scatter of the results is quite acceptable for modern runways and requires no further comment.

The rate of descent at touch-down and the distance of the point of impact along the runway are of course related since if the chosen vertical velocity is small, giving a very smooth landing, the flight path at touch-down is almost tangential to the runway and small disturbances due to variations in wind gradient or turbulence near the ground give a large change in touch-down point. In the tests quoted above the touch-down velocity was set to a mean figure of 2 ft/sec and the rms of the point of impact was 65 yds about a point only 150 yds from the glide path origin. In other words, 68% of all landings occurred within a distance of 130 yds.

It is worth comparing these results with those obtained from the manual landing of a similar jet aircraft in good visibility using the same approach speed (115 knots). In this case 68% of all landings occurred within a distance of 300 yds – more than double the scatter obtained with the automatic system. In a larger jet aircraft the figure increased to almost 400 yds, an increase which would not be expected with the automatic system. It is fair to claim, therefore, that not only will the automatic system land the aircraft when the weather prevents the human pilot, it also performs the operation much more precisely.

It is notable that both British European Airways and British Overseas Airways Corporation in their new aircraft to be built in Britain have stated a requirement for automatic flare-out, i.e. automatic control to touch-down in the vertical plane, with provision for full automatic landing at a later date. The automatic flare-out using radio altimeter as guidance will increase the safety level at the present weather limits and may also lower the limits. It will improve the consistency of landings in marginal conditions and at the same time provide valuable experience on the operation of an automatic control system at low height. It is a very significant step towards the completely automatic system in both vertical and lateral planes, the adoption of which must depend to some extent upon international agreement on the lateral guidance system. BEA and BOAC are the first civil operators to take this step.

**Televiewer**

It has for many years been felt very desirable to present to the pilot in bad visibility a picture in the cockpit similar to the one he would see during a night landing in good visibility. If this could be done, it was felt that perhaps the pilot could make a manual landing using this picture. This would provide a Manual Blind Landing System (i.e. the pilot still in the loop) in contrast to the Automatic Landing System (pilot outside the loop but monitoring) so far discussed. One such independent system is the "Televiewer", the broad principles of which are now discussed.

Flight experiments have been conducted by BLEU initially using various types of visual masks and more recently using a closed-circuit television system installed first in a Devon and later in a Meteor aircraft. The television camera is mounted on the nose of the aircraft and the monitor tube is viewed by the pilot. The experiments, made both by day and night, have shown that a pilot can land satisfactorily an aircraft with an approach speed of 135 knots using a picture of runway lights presented to him on a cathode ray tube, and that this speed is not limiting if the picture is of reasonable quality. They have also established the limits acceptable to the pilot of some of the parameters of the picture.

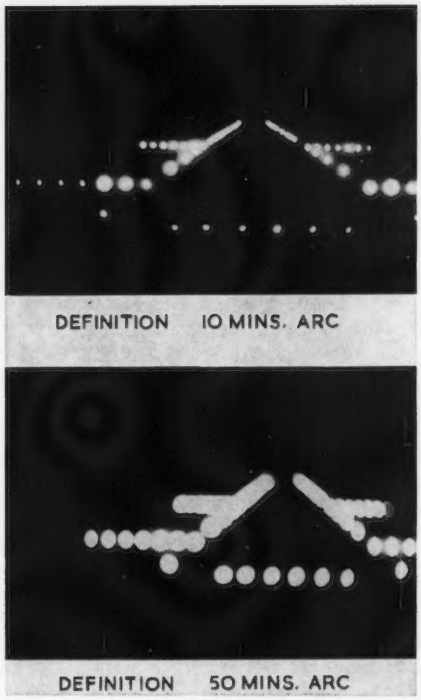



**Figure 20**
**Television experiment typical displays**

As one example of the type of experiment made, Figure 20 shows two photographs of the cathode ray tube viewed by the pilot to obtain the information required to land the aircraft. The tests were made at night and a simple lighting pattern was used to outline the runway and provide the necessary visual guidance. The picture displayed to the pilot has been deliberately degraded to represent the quality likely to be obtained from possible types of Televiewer systems in bad weather. The upper picture represents a static resolution of 10 min of arc whilst the lower picture represents 50 min resolution. Normal visual resolution is about 1 min of arc so the pictures represent definitions about 10 and 50 times worse than is possible with the naked eye. Using 10 min of arc resolutions a large selection of pilots experienced no difficulty in landing at a speed of 135 knots, but with a resolution of 50 min of arc satisfactory landings at this speed were not possible. In this way it was possible to determine the resolution required from the Televiewer system.

The concept of the Televiewer is then as follows. A number of radio beacons are placed in some suitable pattern about the runway, and the aircraft carries a receiver capable of direction finding on each beacon, thereby generating in the aircraft a picture of these beacons on a cathode ray tube. The position of the beacons is measured relative to the aircraft axis, thus giving a picture similar to that seen by the eye through the cockpit windscreen. None of the aircraft's normal flight instruments is used in generating it. Since neither visible light nor infra-red will penetrate fog (as distinct from haze) a radio frequency must be used.

The concept is simple enough, but the difficulty lies in finding an airborne receiver that has at the same time the simplicity and the accuracy of direction finding likely to be required by the civil user. There are many possible types of systems, but the number has been narrowed down by theoretical work at BLEU and experimental work has begun on the more promising ones.

**Visual aids**

Although so far attention has been confined to developments which enable a completely blind landing to be made, the more immediate problems facing civil operators in landing in reduced visibility are not being neglected. The visual landing following an instrument approach to a low height is a critical manoeuvre and much can still be done to ease the load on the pilot and provide him with more precise visual information.

The Calvert centre-line and crossbar approach lighting system is now recognized as providing excellent roll and azimuth guidance during approach but, in common with all other approach patterns, is very limited in the glide path information it provides. Following an analysis of accident statistics, attention has been concentrated recently upon improving the glide path guidance to avoid undershoots. An angle of approach indicator or visual glide path indicator has been developed at RAE which enables the pilot to see immediately his position relative to the desired glide path and if there is an error to stabilise rapidly on the correct approach.

Figure 21 shows the principle of the aid. The indicator consists of two light bars about 30 ft wide on each side of the runway at the fore and aft limits of the desired touch-

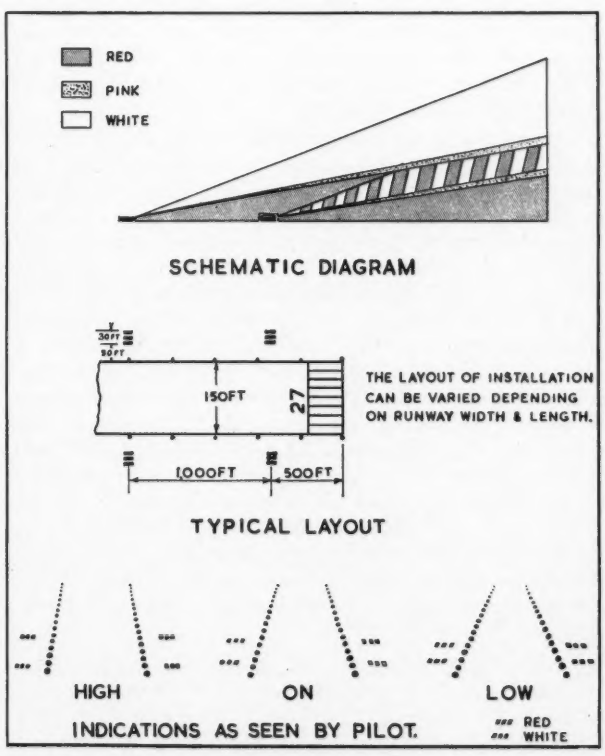



**Figure 21**
**RAE visual glide path indicator**

down area. The lamps are of the sealed beam type with a red filter making the lower half of the beam red. This arrangement gives a pink section ¼° wide between the red and white beams. As the aircraft goes from above to below the glide path the indications seen by the pilot change in the sequence shown in Figure 21. If the aircraft is too high both bars are seen white and if too low both bars are red. Within the desired approach angle limits the furthermost bar will be seen red and the nearer one white. The sensitivity of the aid remains constant in touch-down. In addition the touch-down area is defined and roll guidance at touch-down is provided.

Under the worst daylight conditions – in haze and when approaching the runway into the sun – the indicator lights have been visible in ranges in excess of two miles. At night a range of eight miles is obtained. Extensive flight tests have shown the indications to be clear and positive and arrangements are in hand to instal the aid at several civil airfields, including Belfast, Liverpool and Prestwick, for a full operational evaluation.

## CONCLUSIONS

The very limited review which has been made in this paper does not, of course, emphasize fully the enormous strides in aviation which have been made but it has tried to point the ever-widening vista ahead in the field of commercial air transport.

The two factors which have dominated the military aircraft picture in recent years are, first, the ability to generate nuclear explosions and, second, the successful emergence of the unmanned aeroplane or guided weapon.

The application of these developments is profoundly influencing the shape and nature of military air forces throughout the world. But enormous developments are in prospect in relation to both manned and unmanned flight and it will be very surprising if vital roles for each are not selected in the future.

To return to the more limited scope of this paper, we have briefly reviewed the amazing growth of air transport since its inception and we have examined some of the opportunities which exist for further expansion. A great opportunity exists for expanding passenger traffic in the short stage length services. We have seen how in these services it is not very profitable to increase aircraft speed and this will remain the case until the ground portion of the door to door journey time is substantially reduced. It seems that VTOL, which would, of course, permit aircraft to operate closer to centres of population, may not provide the solution to this problem owing to the economic penalty which its application implies, and owing possibly to the persistence of the noise problem. It is believed that there is opportunity to reduce the indirect and overhead costs of operating short range aircraft and certainly the greater the traffic the less per passenger should these costs be. In some parts of the world, for example, Western Europe, a very great contribution can be made by ensuring a greater regularity and we have shown how this is likely to come to pass as the result of the introduction of blind landing systems. Development in these various directions will justify the introduction of much larger aircraft and this step, in itself, will result in a further reduction in cost per passenger and thereby lead to an even greater attraction of traffic.

Possibly the greatest influence of all in attracting more air passenger traffic will be the continuing improvement in prosperity throughout the world. The powerful trends towards the improvement of the standard of living in backward countries and the opening up and exploitation of the rich natural resources in many countries, of which Canada is an excellent example, are evidence of this growth in prosperity and as it persists the cost of flying will be more easily met by greater and greater numbers of people.

As regards air freight, we have seen how any reduction in cost is likely to lead to a proportionately much higher increase in the traffic. It is believed that substantial reductions in cost can be achieved and one of the ways is to invest in much larger, specially designed freight aircraft, which may eventually operate from special airports equipped with appropriate arrangements to handle efficiently the various kinds of freight.

We have seen how the advance in aerodynamic knowledge has enabled us to visualise much more hopefully the application of laminar flow to aircraft of advanced design, and thereby to enable the costs of aircraft flying long stage lengths to be very substantially reduced. We have also seen how advance in aerodynamic knowledge is enabling us now to visualise long range transport aircraft flying at supersonic speeds with competitive economics. Finally we see, though admittedly somewhat more dimly, that in a sense the sky is no longer the limit – namely that it is not regarded as foolish, even with the ultimate object of air transport in mind, to apply some high quality research effort to the possibilities of flying long distances mainly through the fringes of the atmosphere which surrounds the earth.

There still exists, as there has always done, a most exciting prospect for the further development of atmospheric flight including manned flight with which this paper exclusively deals. It is believed that the cost, convenience, regularity and safety of flying will all greatly improve. It is also believed that world prosperity will steadily increase and that the conjunction of all these factors provides the opportunity to aim to carry by air many times the present volume of traffic.

## ACKNOWLEDGMENT

I wish to express my gratitude to my colleagues at the Royal Aircraft Establishment, in particular, T. V. Somerville and J. Charnley, who have contributed greatly to the preparation of this paper.

## APPENDIX

### SPECIFICATION FOR MILITARY FLYING MACHINE, APRIL, 1908

(1) The machine must have carrying capacity sufficient to carry

(a) Operator — Av. wt. 170 lb
(b) Observer — " " 170 lb
(c) Instruments, maps etc. — " " 10 lb
(d) Fuel for a journey of 4 hours

(2) It must be capable of rising from or descending on to any ordinary open space of grassland or fairly smooth ground of an area of 10 acres without damage to itself or occupants.

(3) It must have an average speed when in the air of not less than 25 mph in a calm (air) which speed it shall maintain for not less than an hour.

(4) It must be capable of rising with its full load to a height of 2,000 ft above its starting point and be able to carry its full load at heights of 5,000 ft above Mean Sea Level.

(5) It must be reasonably steady when under flight in order that observation with field glasses may be made from it.

(6) It must be capable of remaining in the open in all ordinary weather for a period of one month without very material deterioration.

(7) It must be capable of flights of 2 hours duration during which it must describe several circles of varying diameters.

(8) It must be capable of being kept in the air "hovering" or circling over any desired point for periods of a minute or more.

(9) It should be constructed so that if the engine stops from any cause or any portion of the machinery breaks down there shall be a reasonable chance of the occupants reaching the ground in safety.

(10) It must be constructed so that the consumption of its fuel will not upset its stability during flight.

(11) It must be capable of being taken to pieces for carriage on board ship or on rail, and of being reassembled at any desired spot by skilled men within a period of 72 hours.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*Revised October 1959*

# PROPULSION SYSTEMS FOR SPACE TRAVEL†

by Dr. H. S. Ribner*

*University of Toronto*

## SUMMARY

Nonchemical propulsion systems must be considered for interplanetary travel because the chemically-fueled rockets require exorbitant initial weights. A brief survey is given of the salient features of nuclear and solar thermal systems, ion and plasma propulsion, photon propulsion and the isotope "sail". The notion of an optimum (very high) jet velocity for minimum takeoff weight is developed (after Moeckel) and used as a yardstick. The analysis of the isotope sail is perhaps new, the remainder of the material being of a review nature[a].

## INTRODUCTION

It has been demonstrated that present-day chemical rockets are capable of placing satellite stations in orbit around the earth. Chemical rockets require, however, exorbitant takeoff weights to achieve interplanetary travel. We shall discuss, therefore, alternate propulsion schemes for such travel. For many of these schemes, the starting point must be a satellite station by reason of low thrust, as will be shown later.

For a given mission the rockets must supply a certain overall speed gain. Thus the speed must be boosted some 25,000 mph to travel from an earth satellite orbit to the vicinity of Mars. The fundamental rocket equation states that, other things being equal, speed gain is proportional to jet exhaust velocity. Therefore it is very desirable – even imperative – to increase the jet velocity in order to make the overall speed gain sufficiently high with a reasonable takeoff mass.

## JET VELOCITY FOR MINIMUM WEIGHT

Let us attempt to find the optimum jet velocity for a given mission[1, 2]. (See Appendix for details of the analysis.) We specify a certain constant thrust and a certain travel time (strictly speaking, travel time is a weak function of thrust). It can easily be shown then that the required *fuel weight* for the trip goes inversely as the jet velocity. On the other hand, the required *engine weight* may be assumed, perhaps, proportional to the power expended in the jet. It follows that engine weight, for fixed thrust, is directly proportional to jet velocity. Thus fuel weight is inversely proportional, and engine weight directly proportional to jet velocity.

The sum fuel weight plus engine weight passes through a minimum as jet velocity is varied. This minimum weight is achieved, it turns out, for an optimum jet velocity, which

$$\sim \sqrt{\text{travel time} \times \text{kw/lb engine wt.}}$$

As an example, consider a Mars trip of 450 days, with a powerplant of 10 lb/jet kw. In this case the optimum jet velocity is around 300,000 mph. The equations for this case show further[2] that $thrust/gross\ weight \approx 10^{-4}$. This is more or less typical when we optimize for minimum weight (not for minimum energy)[1].

This tiny thrust of 1 lb for every 10,000 of gross vehicle weight may seem surprising to some. It certainly would not take a ship off the ground, but it will suffice for a takeoff from a satellite orbit or space station, and if maintained for many, many months it can produce the required amounts of speed.

## THERMAL SYSTEMS

We come now to specific kinds of propulsion systems. By consideration of the kinetic energy in the jet, we see that the total energy for the trip goes as the square of the jet velocity for a given fuel weight. With our proposed large increases in jet velocity, chemical

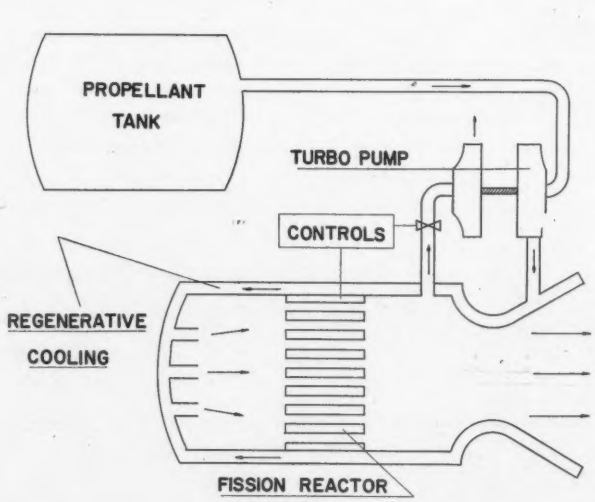


**Figure 1**
**Rocket with solid fission heat source**

†Based on a paper read at a meeting of the Astronautics Section of the C.A.I. in Ottawa on the 9th October, 1958.

*Associate Professor, Institute of Aerophysics.

[a]For a much more comprehensive review on a higher technical level, see W. E. Moeckel's paper[3], which became available after the main body of this paper was prepared.

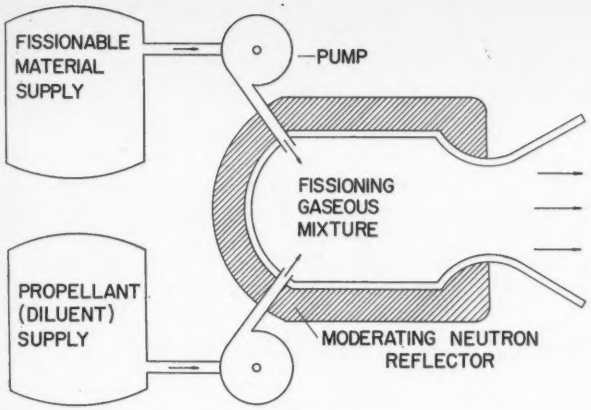


**Figure 2**
**Rocket with gaseous fission heat source**

energy is far too small. We look to nuclear energy or solar energy.

What we may call thermal systems employ nuclear or solar energy in the form of heat[3, 4]. An example scheme is shown in Figure 1. We have a fission heat source, a propellant injector, a heat exchanger to heat the propellant and a nozzle to form a high speed jet. Alternatively (Figure 2), in the so-called "fizzler" nuclear jet the gas is heated directly, without a heat exchanger. In a third arrangement[4] the fission-heated gas is employed in a shock-tube cycle (Figure 3), involving a sequential operation of quick-acting valves. In other schemes under study the heat is used to generate electric power by means of rotating equipment. This power can be used to generate an electric arc in the very effective scheme of Figure 4. Bussard and DeLauer[4] estimate velocities of the order of 100,000 mph continuously with arc heating.

Other heat sources are the mentioned solar heating, nuclear fusion and radioisotopes. With solar heating focusing mirrors (e.g. half-silvered polyethylene balloons as suggested by Krafft Ehricke[5]) of very large diameter are required.

The thermal systems face the enormous problem of containing the extreme temperatures associated with very high jet speeds (e.g. $10^5$°R)[4]. Nozzles will tend to vaporize. At high powers nozzle cooling systems will remove so much power that any added power will all go

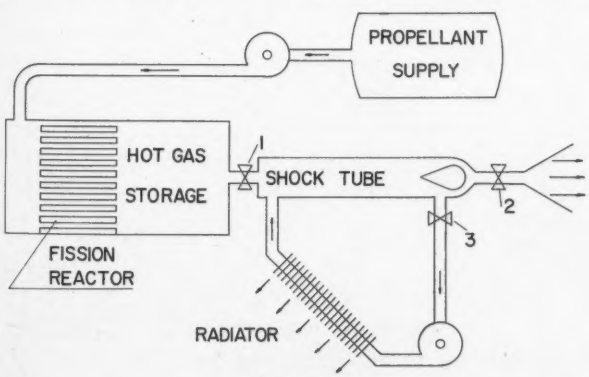


**Figure 3**
**Fission-shock tube propulsion system**

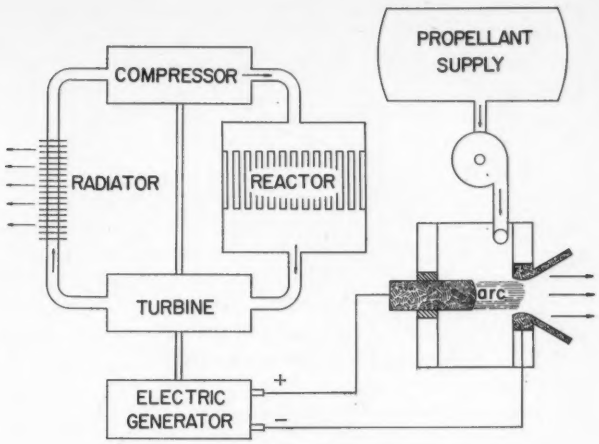


**Figure 4**
**Electric-arc rocket**

out in the coolant. These considerations, according to Reference 2, will limit the attainable jet velocity with the electric arc to the order of 65,000 mph, unless schemes of magnetohydrodynamic containment — i.e. pinch effect — are worked out to keep the hot jet from contact with the nozzle walls. Schemes employing the pinch effect are discussed and shown schematically in Reference 1.

**ION PROPULSION**

The electrode and nozzle heating problems can be bypassed by using an electric field for accelerating ionized particles to constitute the jet. This is ion propulsion[3]. A schematic arrangement is shown in Figure 5. By employing high-voltage electrodes in this fashion the ions can be accelerated in a beam to hundreds of thousands of miles per hour. It is to be noted that a companion beam of electrons will be required to avoid space-charge buildup. Alternatively, the electrons can be admixed with the positive beam after acceleration in a scheme for positive ion generation due to Stuhlinger[6].

The ion propulsion schemes require large electric current densities. It is difficult to obtain suitably rich ion sources, and there is an additional space-charge limitation

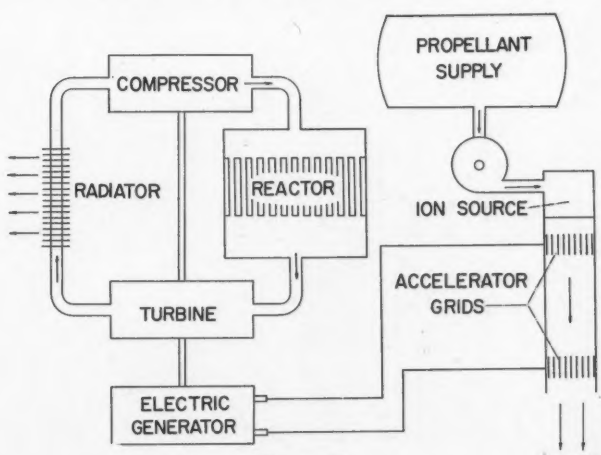


**Figure 5**
**Ion-propulsion system**

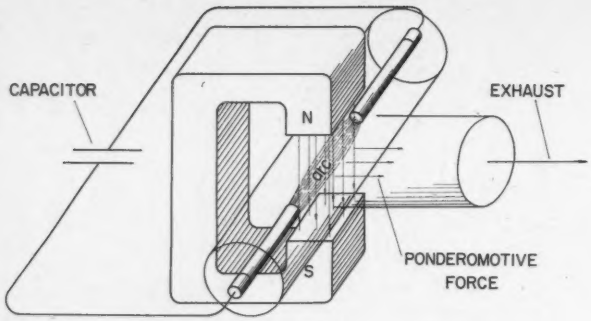


**Figure 6**
**Plasma propulsion system (Kolb)**

on current density. The admixture of electrons, mentioned above, is intended to alleviate the space-charge limitation.

**PLASMA PROPULSION**

Magnetic or plasma accelerators[1] may perhaps circumvent the difficulties associated with ion propulsion, although introducing others in their stead. A particular scheme due to Kolb[7] is shown in Figure 6. A condenser at high voltage strikes an arc in low density gas. The arc is a plasma, a highly ionized gas: it is a conductor. We have a conductor carrying current at right angles to a magnetic field. So this conductor – the plasma – is violently expelled to the right by electric dynamo action. (A thermally produced shock wave also plays a part.) The reaction provides thrust. This system may be cycled to give a pulse-jet action.

No special ion source is needed: the arc breakdown creates the ions. Very heavy effective current densities seem obtainable. Also, the plasma system is electrically neutral: no matching of electron beams to positive ion beams is required.

There are many variants of the scheme for magnetic propulsion of plasmas. The so-called Bostick "button"[8] is of interest (Figure 7). The plasma comes not from a gas, but from the material of the electrodes operating

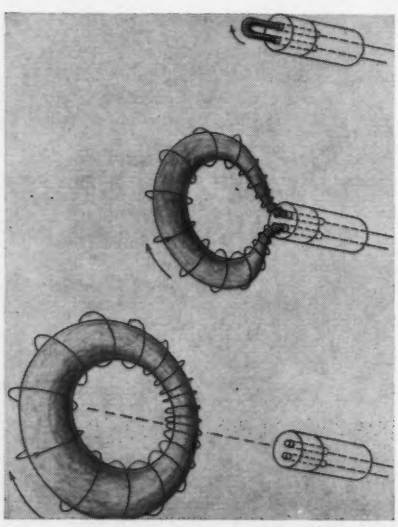

**Figure 7**
**Plasma propulsion system (Bostick)**

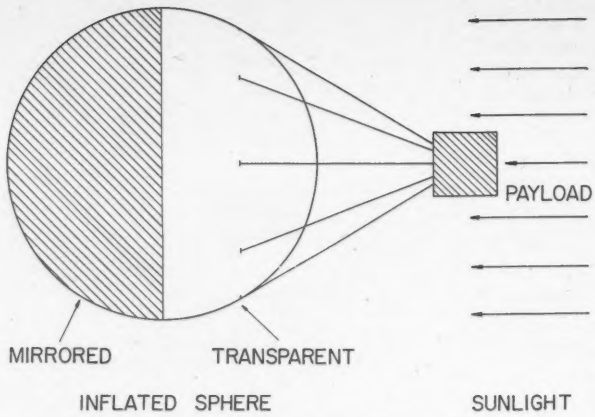


**Figure 8**
**Solar sail employing half-silvered balloon of Ehricke**

in a vacuum. Here the gradient of the arc's own magnetic field propels a doughnut of plasma, called a "plasmoid". (Bostick thinks his plasmoids, in their interaction with external magnetic fields, may simulate features of the formation of galaxies.)

**PHOTON PROPULSION**

Leaving ions, we come now to jets consisting of photons; that is, our jets are just beams of light or even radio waves. Photons possess momentum and they move with the speed of light. Our previous analysis shows that the speed of light is far above optimum, and the energy requirements for such a beam to have appreciable thrust are enormously high. An associated difficulty is that an almost perfect mirror, reflecting many thousands of times the light it absorbs as heat, would be required; this is on the assumption the jet cross-section per unit thrust is not unduly large (e.g. 10 ft²/lb), and it is necessary to ensure that the mirror surface shall not be vaporized by the heat. Hence, I think nuclear-photon propulsion must be ruled out. But solar heating is still in the picture.

The foregoing remarks apply basically to powered photon propulsion wherein a nuclear powerplant supplies energy for the photon beam. Consider, however, the photon 'sail', which in effect sails in the wind of photons emitted by the sun. This avoids many of the difficulties. A scheme that embodies ideas due to Ehricke[5] and NACA[9] is shown in Figure 8. NACA's figures imply

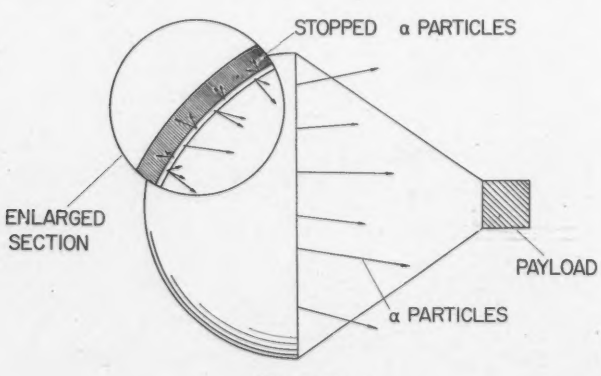


**Figure 9**
**Isotope sail**

that a reflective sail about a half-mile in diameter would be necessary to achieve a total thrust of only one pound; this is for sunlight of the intensity received on the earth. The situation improves, of course, at the orbits of Venus or Mercury.

### ISOTOPE 'SAIL'[9]

The scheme shown in Figure 9 has some attractive features. A radioisotope emitting α-particles of the required high speeds is painted on the inner surface of the thin plastic sail. Those particles emitted toward the sail are stopped and generate heat; those particles emitted away from the sail give up momentum and impart thrust. I estimate (see Appendix) that the effective jet power is about one-fourth of the power that must be dissipated as heat; this implies an effective overall mechanical-thermal efficiency of 20%. This efficiency sounds as good as the best nuclear-ion or nuclear-plasma systems can hope to achieve – and all this with utmost simplicity and no moving parts. On the debit side, however, it appears that the weight of radioisotope required in ratio to the thrust may be rather high. (NACA's estimate[9] seems more optimistic than implied by Reference 4, p. 318.)

## APPENDIX

### JET VELOCITY FOR MINIMUM WEIGHT: DETAILS OF THE ANALYSIS
**(Adapted from References 1 and 2)**

Let $M$ = total mass of propellant
$M'$ = total mass of engine
$m$ = propellant mass flow rate (assumed constant)
$V$ = jet efflux velocity
$t$ = travel time
$T$ = thrust (assumed constant)
$P$ = power expended in jet

Values of $m$, $V$, $T$, $P$ are assumed constant throughout the journey.

Then

$$M = mt$$
$$T = mV \tag{1}$$
$$M = Tt/V$$

Also

$$P = (1/2)mV^2 = (1/2)TV \tag{2}$$

Assume mass of engine ~ jet power:

$$M' = \alpha P = (1/2)\alpha TV; \quad \alpha \text{ in slugs/ft-lb/sec} \tag{3}$$

Then

$$M + M' = T[(t/V) + (1/2)\alpha V] \tag{4}$$

This mass is a minimum (neglecting the weak dependence of $t$ on $V$ for a given journey) when

$$\delta(M + M')/\delta V = 0 = T[(-t/V^2) + \alpha/2]$$

or when

$$V = \sqrt{2T/\alpha} \tag{5}$$

or

$$V \sim \sqrt{\text{travel time} \times \text{kw/lb engine wt.}}$$

### SIMPLIFIED THEORY OF THE ISOTOPE SAIL

Assume each tiny piece of radioisotope emits particles (e.g. α-particles) uniformly in all directions with radial velocity $V$. Assume the particles in the forward hemisphere are stopped by the sail; then only those in the rear hemisphere escape: let this mass flow rate, summed over all the emitters, be $m$. If the normal to the sail (assumed plane) is the $x$-direction, then the total $x$-momentum carried by the particles (which equals the thrust) can be shown to be

$$T = \int_0^{\pi/2} mv \sin\theta \cos\theta \, d\theta$$

where $\theta$ is the polar angle measured from the $x$-axis. Finally, the thrust is

$$T = (1/2)mv \tag{6}$$

The flux of kinetic energy through *either* hemisphere is

$$P_1 = (1/2)mv^2 \tag{7}$$

This amount of power must be dissipated as heat in the sail. At the equilibrium sail temperature an equal amount of heat power is radiated into space.

An equivalent axial jet (or collimated jet) of the same thrust $T$ and mass flow $m$ satisfies

$$T = mV; \quad V = v/2 \tag{8}$$
$$P_2 = (1/2)mV^2 = (1/8)mv^2$$
$$\therefore P_2 = (1/4)P_1 \tag{9}$$

From the viewpoint of cooling requirements we define an "effective" efficiency as the ratio

$$\eta = \frac{\text{jet power}}{\text{power dissipated as heat} + \text{jet power}}$$
$$= \frac{(1/4)P_1}{P_1 + (1/4)P_1} = \frac{1}{5} \text{ or } 20\% \tag{10}$$

In this definition an amount of $\frac{3}{4}P_1$ of waste kinetic energy has been omitted from the denominator: this waste energy is dispersed in space and does not enter into the cooling considerations.

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(9) Aviation Week, August 25, 1958, p 37.


# FILM LIST

The Institute is engaged in the preparation of a concise List of aviation films for the use of its Branches and Sections and by other organizations interested in obtaining films on aeronautical subjects. The work is being undertaken in collaboration with the Air Industries and Transport Association and the Canadian Owners and Pilots Association and, therefore, the List will include films on flying training, meteorology, and other aspects of aviation, as well as engineering.

Several lists of aviation films are already available, but they include a great deal of obsolete material and they probably omit many interesting technical films, held by research organizations and the like, which might be procurable by special arrangement for showing to restricted and qualified audiences. Furthermore, it is not possible to classify films intelligently from the titles and brief descriptions usually given in these lists. Consequently any consolidation of the existing lists would contribute nothing; the proposed List must be based upon first-hand reports.

Since it is clearly impractical to set up a Selection Committee to review, assess and classify all the films which might be of interest, all members of the Institute are asked to cooperate in this work. Any member having personal knowledge of a film which, in his opinion, would be of instructive or of current interest to an aviation audience is asked to send particulars to the Secretary of the Institute.

To ensure that the particulars reported are those needed in the listing, a special report form or "check sheet" has been prepared; these forms are available from the Chairmen of Branch Programmes Committees and from C.A.I. Headquarters.

# C.A.I. LOG

## SECRETARY'S LETTER

### APPLICATION FORMS

It has been suggested that there are not enough application forms about. Of course, the Branch Secretaries have supplies but Branch Secretaries are not always immediately available, and members have told me of some of their most promising "sales pitches" being brought to nought at the last moment, for the want of the necessary pieces of paper. I know personally of one case where a would-be member, having been duly persuaded that he ought to join, had to wait three weeks while his persuader found an application form for him; fortunately, in this case, his enthusiasm did not wane in the meantime. But it well might have done so.

For this reason we are distributing application forms with this issue of the Journal. Thus every member will have a form handy and I suggest that every member should try to make it his good deed for the year to persuade a friend to fill it up and send it in.

### STUDENTS

Every year we lose a great many Student members. I am glad to say that by far the greater part of this loss is attributable to their qualifying for the grade of Technical Member, applying for advancement in grade and being duly advanced; they are not lost to the Institute, only to our Student membership; and this is as it should be. (Of course, a few who have graduated decide to follow some other branch of engineering or science; we are sorry to see them go but, clearly, membership of the Institute no longer holds much appeal to them.)

However it is important that this annual loss of Student members should be made good; for they are the future members of the Institute and, more essentially, the future man-power of Canadian aviation. A year or two ago everybody began to panic about the shortcomings of aeronautical engineering training in Canada and emergency measures were taken to improve the situation. Now that the situation is improving, the demand to some extent has fallen off. But let us not be fooled; the demand can blow up again as quickly as it subsided and we must keep our student body strong; we must remember that it takes three or four years to produce a graduate. I would urge everyone in contact with engineering students to try to encourage them to join the Institute, where they will get some feel of the aeronautical profession. Probably the most effective missionaries we have are those who are already Student members; not only can they explain the advantages of membership to their non-member fellow-students but, the more recruits they can bring in, the more worthwhile their own Student Sections will become.

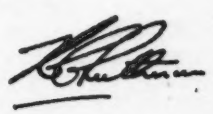
And, speaking of Student Sections, I hope that in the coming season the Branches having such Sections attached to them will do their utmost to encourage and develop them. They are a responsibility which must be fulfilled.

### CHRISTMAS CARDS

In this issue we carry a notice about CAI Christmas Cards – by the November issue it will be getting a little late. In the past we have had some quite complimentary remarks about our Christmas Cards and this year they will be even better; and they are not at all expensive compared with the ordinary things you buy in shops.

### "IT'S A BOO- . . ."

Though this letter is perhaps not quite the appropriate place to record historic happenings, I think that somewhere in the Journal we should make mention of the Russians' successful shot at the moon. Though to my mind it was not so significant an event as the launching of Sputnik I, it was certainly a milestone in history. The sudden cessation of regular signals from a vehicle is usually rather disturbing; probably never before has such a silence been so dramatic or gratifying.



# BRANCHES

## NEWS

### Vancouver

Reported by J. W. Whiskin

*September Meeting*

The Branch held its first meeting of the season in the RCAF Officers' Mess, Sea Island, at 8.00 pm on the 16th September. The attendance numbered 25 members and 4 guests.

The Chairman, Mr. J. R. S. Hutton, opened the meeting by conducting a short business session outlining the summer activities and the programme for the coming year. This was followed, after a short break, by three very good films:

"Transonic Flight" the second of a series of theory of flight films, produced by the Shell Oil Co. This film gives comprehensive explanations for instability, shock waves and other problems encountered in flight at transonic speeds.

"Tomorrow is Theirs" a British Overseas Airways Corporation film outlining the many facets of airline operation.

"Coupes des Alps" a film, produced by the Shell Oil Co., showing sports car racing in the Alps.

After the showing of the films, which were very well received by those present, Mr. Bingham, the Programmes Chairman, thanked Mr. Parry for making the films available and for operating the projector.

### Montreal

Reported by J. R. Chadborn

*Golf Tournament*

The Sixth Annual Golf Tournament was held on Friday, August 21st at St. Andrews Country Club. It was a perfect golf day and, due to previous rain, the course was in excellent condition. Eighty-four members and guests played golf and a buffet dinner was served to eighty-seven.

*Drew*

**Mr. R. F. O. Smith, Chairman, (r) presenting the E. B. Schaefer Memorial Trophy to S/L M. T. Friedl**

Mr. R. F. O. Smith, Chairman, welcomed the assembly and handed the proceedings over to the writer.

The presentation of prizes was carried out with the able assistance of Mr. D. Stevens. The E. B. Schaefer Memorial Trophy, which is awarded annually to the player whether member or guest who posts the lowest gross score, was again won by S/L M. T. Friedl with a score of 83. (Incidentally this is the same score he won with last year.)

The Bob Wright Memorial Trophy was won by Mr. D. McLaren with a score of 84 (low gross) and the winner of the Ross Trophy for guests was Mr. T. Carlisle with a score of 83 (low gross).

*Drew*

**And the Bob Wright Memorial Trophy to Mr. D. McLaren**

The Tournament was apparently enjoyed by all participants and the buffet style dinner once again proved successful in eliminating lengthy waiting for everyone to sit down.

In closing this report, I wish to thank the Ticket Committee for their usual sterling support.

### Toronto

Reported by C. F. deJersey

*September Meeting*

The first meeting of the 1959-60 Season was held in the Cafeteria of the De Havilland Aircraft of Canada Limited, at 8.15 pm on the 16th September.

Dr. J. H. T. Wade, Branch Chairman, welcomed 38 members and 14 guests to the meeting. Attendance was one of the smallest on record; however, it is hoped that the reason was conflicting local attractions, e.g., Ottawa-Toronto Football, major local Motor Club Rally, etc, and not an indication of possible future attendance figures.

The speaker for the evening, Mr. D. N. Kendall, President of the Photographic Survey Corporation Limited, was introduced by the Chairman. Mr. Kendall, the 1959 W. Rupert Turnbull lecturer, delivered his paper on "Air Survey – The Key to Natural Resources".

(The W. Rupert Turnbull Lecture is reproduced on pages 311 to 318 – Sec.)

Considering the small attendance, the discussion period which followed was exceptionally lively. Mr. J. Eames thanked the speaker on behalf of those present.

The Chairman concluded the meeting by high-lighting the programme proposed by the Toronto Branch and gave details of the events to take place in October. These include a visit by the delegates to the Seventh Anglo-American Conference, a field trip to the Institute of Aerophysics and a meeting to hear a speaker from the Maritime Air Command.

# MEMBERS

## NEWS

**G/C B. R. Brown, A.F.C.A.I.,** formerly Deputy Director-General of Medical Services (Air) at AFHQ has been appointed Commanding Officer of the National Defence Hospital at RCAF Station Rockcliffe.

**J. A. McKillop, A.F.C.A.I.,** has been appointed Managing Director of the newly formed Engineering Research Associates, Lorne Park, Ontario.

**C. C. Baker, M.C.A.I.,** has taken a position as Senior Design Engineer with Lockheed Aircraft Corporation, Marietta, Georgia.

**F. R. Charles, M.C.A.I.,** formerly Acting General Counsel and Chief Patents Officer of NRC, has been appointed General Counsel. He has also been elected Secretary-Treasurer of Canadian Patents and Development Ltd.

**J. E. Fox, M.C.A.I.,** has been transferred to the Missiles and Space Division of the Lockheed Aircraft Corporation at Sunnyvale, California.

**G. C. Legg, M.C.A.I.,**formerly with Avro Aircraft Ltd., is now Project Engineer with S. F. Bowser, Hamilton, Ontario.

**G. E. A. Thomann, M.C.A.I.,** has been appointed principal engineering partner in charge of Structures in the newly formed company of Engineering Research Associates.

**R. P. Wade, M.C.A.I.,** has taken a position as Senior Structures Engineer with Convair Aircraft Corporation, San Diego, California.

**H. F. Young, M.C.A.I.,** formerly Chief Production Engineer, Steel Fabrication and Manufacturing Division, Dominion Steel and Coal Corporation Ltd., in Montreal, has recently been appointed General Manager.

**L. Box, Technical Member,** has been appointed Manager of Administrative Services within the Missile Group at Canadair Ltd.

**S. Bruskiewich, Technical Member,** has taken a position wtih Algoma Engineering Limited in Edmonton, Alberta.

## ADMISSIONS

At a meeting of the Admissions Committee, held on 26th August, 1959, the following were admitted to the grades shown.

### *Associate Fellow*

**J. A. McKillop,** Chief of Performance Evaluation, Avro Aircraft Ltd., Malton, Ont.: *Box 266, Lorne Park, Ont.*

### *Member*

**S. B. Brown,** Defence Scientific Service Officer, Defence Research Board, Ottawa, Ont.: *255 Metcalfe St., Apt. 58, Ottawa, Ont.*

**J. Cassidy,** Aircraft Maintenance Engineer, Bristol Aero-Industries Ltd., Montreal Airport, Dorval, P.Q.

**V. Caswell,** Service & Sales Representative, Canadair Ltd., Montreal, P.Q.: *8 Lakeview Rd., Baie D'Urfee, P.Q.*

**L. A. Dickinson,** Group Leader, Rocket Engine and Propellant Development, C.A.R.D.E., Valcartier, P.Q.: *51 Des Talus, Quebec 10, P.Q.*

**D. W. H. Godfrey,** Asst. Manager, Information Services Dept., Canadair Ltd., Montreal, P.Q.: *5320 Dudemaine St., Apt. 8, Montreal, P.Q.*

**F. Halpin,** Asst. Manager, Aviation Div., Walter Kidde Co. of Canada, 5500 Royalmount Ave., Montreal 9, P.Q.

**A. J. Henderson,** Aircraft Maintenance Engineer, Bristol Aero-Industries Ltd., Montreal, P.Q.: *18 Harlow Cresc., Thistletown, Ont.*

**S/L J. G. McManus, RCAF,** Aircraft Project Engineer, Air Material Command, RCAF Stn. Rockcliffe, Ottawa, Ont.: *655 Windermere Ave., Ottawa, Ont.*

### *Technical Member*

**B. Ashikian,** Inspector, Aircraft Industries of Canada Ltd., St. Johns, P.Q.: *Rg. St. Michel (Route 7). Iberville, P.Q.*

**J. M. Barrie,** Powerplant Assembler, De Havilland Aircraft of Canada Ltd., Downsview, Ont.: *428 Summerville Ave., Toronto 5, Ont.*

**W. G. Clarkson,** Vice-President and Gen. Manager, Anderson-Macbeth Ltd., Toronto, Ont.: *32 Arthur St., Weston, Ont.*

### *Student*

**W. I. Mitchell,** Provincial Institute of Technology and Art, Calgary, Alta.: *Box 642, Rosetown, Sask.*

* * *

At a meeting of the Admissions Committee, held on the 2nd September, 1959, the following were admitted to the grades shown.

### *Associate Fellow*

**CDR E. B. Morris** (on transfer from Member)

### *Member*

**W. S. Bellian** (on transfer from Technical Member)

**W. E. Regan,** Technician, Canadian Pacific Air Lines Ltd., Vancouver, B.C.: *967 Pinwell Cresc., Richmond, B.C.*

**A. B. Stevens,** Engineer Missiles and Systems Div., Canadair Ltd., Montreal, P.Q.: *220 - Seventh Ave., St. Eustache, P.Q.*

### *Technical Member*

**C. A. Peters,** Sales and Service Rep., Carriere and MacFeeters Ltd., Scarborough, Ont.: *304 Dovedale Dr., Whitby, Ont.*

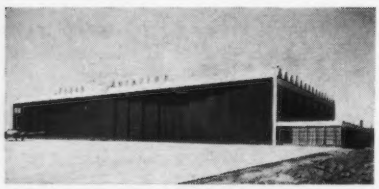
**F/O W. A. Petersen** (on transfer from Student)

**J. P. Vaillancourt,** Aero. Engineer, Civil Aviation Br., Dept. of Transport, Ottawa, Ont.: *102 Cobourg St., Ottawa, Ont.*

### *Junior Member*

**J. W. Pfeiffer,** Engineering Assistant, Pacific Western Airlines, Edmonton, Alta.: *8720 - 82nd Ave., Edmonton, Alta.*

# SUSTAINING MEMBERS



**Field Aviation Company Limited** has completed a unique new hangar at Calgary Municipal Airport, which will service corporate aircraft operating in the Calgary area. With 53,000 sq ft of floor space, the $750,000 building is constructed of pre-stressed concrete and is virtually fireproof. Power-operated doors provide 32 ft-high, 250 ft-wide access to hangar, which will accommodate aircraft as large as the Super-Constellation. Also unusual in the new hangar is the gas-fired, infra-red radiant heating which heats objects rather than air space, reducing loss of heat when hangar doors are open. A large part of the hangar space has already been leased to oil companies and other corporations operating executive aircraft. A structure adjoining the main building houses lounge, office space and machine shops.

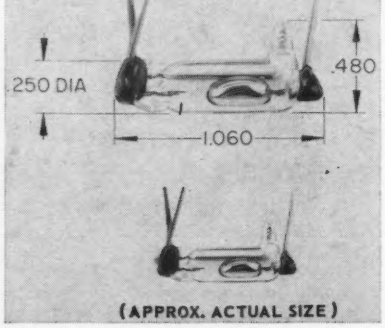
**Honeywell Controls Limited** have announced that Micro-Switch, Toronto, a division of theirs, have introduced two new switches. These are:

(a) A new low-angle mercury switch designed to meet the precise requirements of vertical gyros, stable platforms and rocket guidance systems.

The switch (designated AS603AI) weighs only 3.8 grams, including three 7-inch Teflon-insulated leads. It features a different angle of 0.15 degrees maximum and a mass shift of 0.085 grams-centimeter, which, according to the company, makes it the most sensitive mercury switch ever developed.

Trouble-free operation is assured. Hermetic sealing of the glass tube prevents dust, dirt and corrosive vapors from fouling contacts.

Contact arrangement is single-pole, double-throw. The switch is electrically rated for 0.255 amp., max., 30 vac. 400 cps, for an inductive load.




**AS603AI Switch**

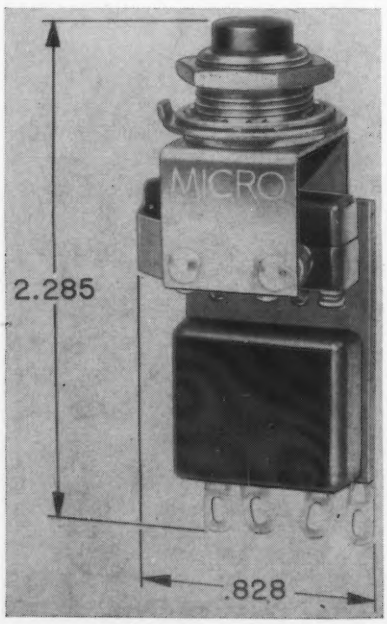
(b) A new series of pushbutton switch assemblies, incorporating an electronic circuit to produce a single, microsecond-length pulse with each operation.

The capabilities of this 1PB600 series of "one-shot" switches are claimed to eliminate the need of designing special pulse input circuits for high-speed electronic switching devices. The square wave pulse width is factory adjustable from 0.25 to 2.5 microseconds and the amplitude from 3 to 60 volts.

Both width and amplitude are independent of the speed of switch operation. No standby power is required.

The switches, which will operate in a temperature range of −65° to +185°F, are designed for use in electronic test circuits, keyboard input consoles, fusing arming and firing circuits and reflected pulse systems.

The electronic circuit used in the new switches includes a capacitor, resistor, magnetic core and diode. All components are potted in a modular package to provide physical and environmental protection. Contact arrangement is single-pole double-throw.




**1PB600 Series**


## CHRISTMAS CARDS

bearing the **C.A.I. Crest** in full colour,

are available to members at the following prices:

**15c each** **$1.25 for ten** **$5.50 for fifty**

*(Prices include envelopes)*

Orders, with appropriate remittance, should be sent to

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Canadian Aeronautical Institute,
801 Commonwealth Building,
77 Metcalfe Street,
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## SUSTAINING MEMBERS

## of the

## CANADIAN AERONAUTICAL INSTITUTE

## 1959-60

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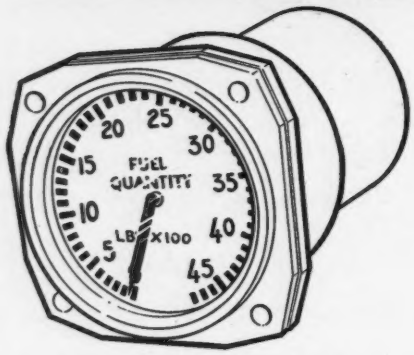


A new, lighter, more accurate and reliable two-unit design for present and future needs. Features: Fiberglas tank unit and combined indicator — amplifier-bridge, fuel compensation, sequencing, and operation of auxiliary devices.

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## APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No. to which enquiries may be addressed (c/o The Secretary) will be assigned to each notice submitted by an individual.

The Institute reservers the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.

# SPECIALIST SECTIONS
# MEMBERSHIP REQUIREMENTS

At the present time there are three Specialist Sections of the Canadian Aeronautical Institute. To be a member of a Section, it is necessary firstly to be a member of the Institute and secondly to possess certain qualifications peculiar to the Section concerned. These identifying qualifications are set out in the following extracts from Section Regulations.

### TEST PILOT SECTION

All members of the Institute who are or have been engaged as pilots in experimental, development, production or maintenance flight testing shall be eligible for membership of this Section.

### PROPULSION SECTION

All members of the Institute who are or have been engaged in technical work on propulsion systems shall be eligible for membership of the Section.

### ASTRONAUTICS SECTION

All members of the Institute who are or have been engaged in technical work related to guided flight or space vehicles or who possess technical knowledge of the science and engineering of astronautics shall be eligible for membership of the Section.

Any member of the Institute wishing to be admitted to a Section should apply on a special form which can be obtained from Branch Secretaries or from C.A.I. Headquarters.

Membership of a Section does not entail the payment of any entrance fee or annual dues additional to those normally payable for membership of the Institute.

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# reliability is key to success of giant satellite!

## Lord mounting systems played critical role in record-breaking feat

THE Advanced Research Projects Agency of the Air Force and Convair Astronautics, prime contractor, can take pride in this latest Atlas accomplishment.

It is no coincidence that Convair chose LORD high-performance mounting systems for reliable protection of sensitive electronic control equipment.

This giant leap toward the stars demonstrates LORD capabilities to produce custom-designed mounting systems of uncompromising excellence.

High-performance mounting system for Atlas protects electronic packages by providing protection from destructive shock, vibration and noise. It is a product of Lord's integrated systems engineering approach.

Successful Atlas launching on December 18, 1958 put 4-ton satellite into orbit.
USAF photo courtesy Convair Astronautics

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# ROLLS-ROYCE BY-PASS JETS

## are now flying in Boeing 707-420 and Douglas DC-8 jet airliners

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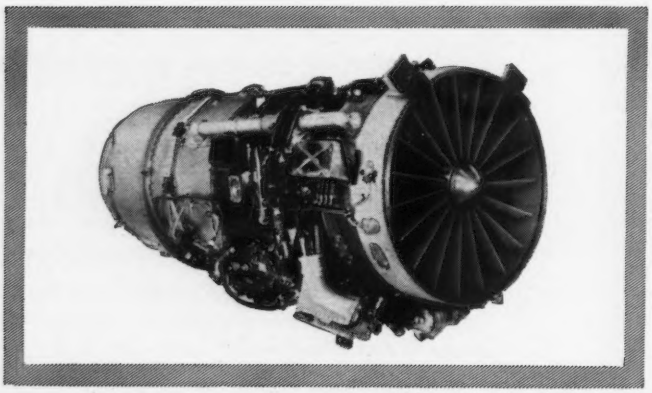
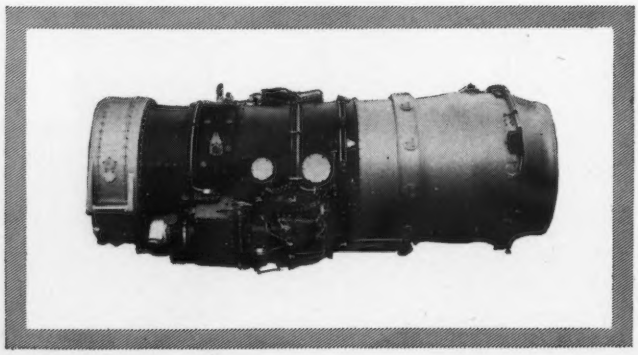


Conway by-pass jets for civil use will enter service in 1960 at 17,500 lb. guaranteed minimum thrust. The Civil Conway is being developed to powers over 20,000 lb. thrust with improved fuel consumption.

The RB. 141 family of by-pass jets (10,000 lb. to 17,500 lb. thrust) have been designed to give the best possible operating economics for jet transport aircraft. The RB.141 of 14,300 lb. thrust will power later versions of the Sud-Aviation Caravelle and the RB.163 of 10,100 lb. thrust has been chosen to power the Airco DH.121.



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As the Canadian Affiliate of the Bendix Aviation Corporation, AEL also sells and services a wide range of aircraft and marine products, communications equipment, and specialized industrial equipment.

AEL serves the Department of Defence, R.C.A.F., R.C.N., leading aircraft manufacturers, leading airlines, as well as smaller air service companies and many private aircraft owners.

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# JARRY
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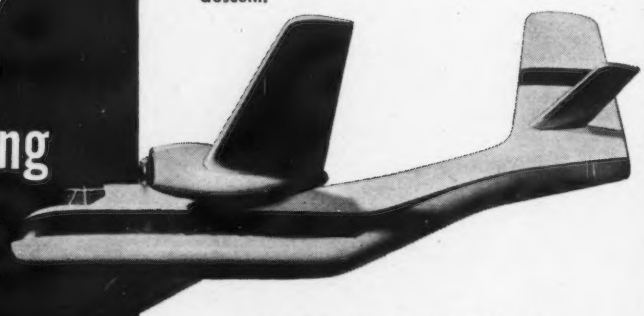
**STOL LANDING GEAR**

Developed by Jarry for De Havilland's *Caribou*, this landing gear permits landings in unprepared fields at high rates of vertical descent.



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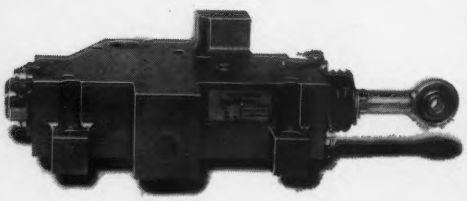
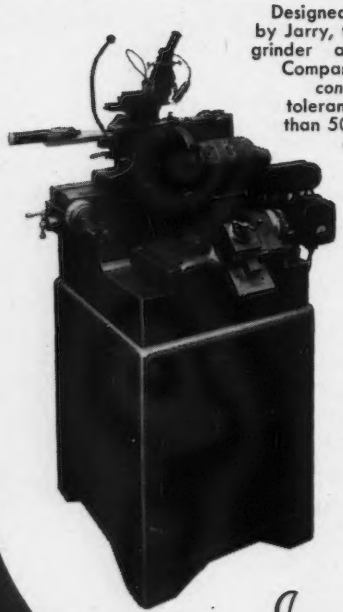
Designed for a 4000 psi system with such advanced characteristics that many valve manufacturers dubbed it "impossible" to make.



**MILLICRON MATCH GRINDER**

Designed and built by Jarry, this unique grinder allows the Company to work *consistently to* tolerances of less than 50 millionths of an inch.



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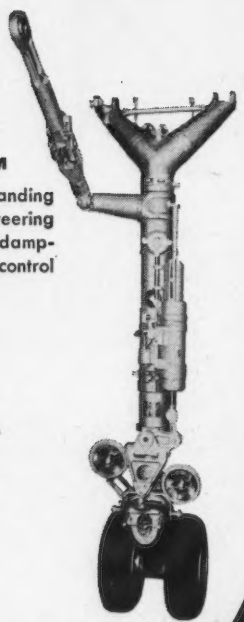

**Perhaps we can be helpful to you.**

*Designers and manufacturers of landing gear and other hydraulic components for modern aircraft including: Argus, Arrow, CS-2F-1, F-86, T-33, Beaver, Otter, Caribou, CL-41, CL-44, CL-46.*

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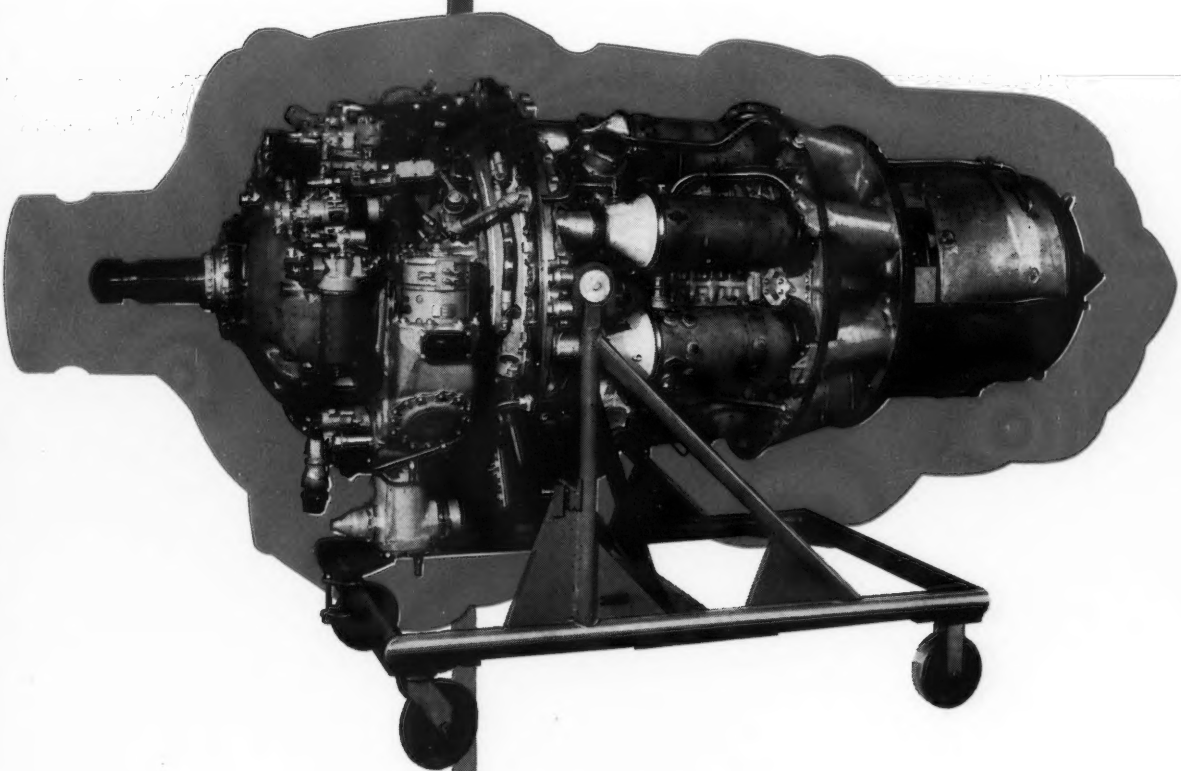
## overhauling turbo-prop engines and components for world airlines



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*Fourth in a series on the aircraft and engine overhaul, servicing and manufacturing facilities of Bristol Aero-Industries Limited.*